Volume 15 SEPTEMBER 1931 Number 9

BULLETIN
of the
American Association *of* Petroleum Geologists

CONTENTS

Permo-Carboniferous Orogeny in South-Central United States
By W. A. J. M. van Waterschoot van der Gracht 991

Pre-Carboniferous Stratigraphy of Marathon Uplift, West Texas
By Philip B. King 1059

Detailed Cross Section from Yates Area, Pecos County, Texas, into Southeastern New Mexico *By H. P. Bybee, E. F. Boehms, Cary P. Butcher, H. A. Hemphill, and G. E. Green* 1087

Geological Notes

Supposed Marine Jurassic (Sundance) in Foothills of Front Range of Colorado *John B. Reeside, Jr.* 1095

Silicified Shell Fragments as an Indication of Unconformity *J. V. Howell* 1103

Discussion

Bearing of Cap Rock on Subsidence on Clay Creek Salt Dome, Washington County, Texas, and Chestnut Dome, Natchitoches Parish, Louisiana *Marcus I. Goldman* 1105

Clay Creek Salt Dome, Washington County, Texas *Frederic H. Lahee* 1113

Reviews and New Publications

Physics of the Earth—II. The Figure of the Earth *National Academy of Sciences* (B. B. Weatherby) 1117

Recent Publications 1118

The Association Round Table

Supplementary Membership List 1119

At Home and Abroad

Current News and Personal Items of the Profession 1121

Copyright, 1931, by The American Association of Petroleum Geologists, Inc.

CORES—
Cable Tool or Rotary—
Exploration or Confirmation

Looking at the matter from your side, what is it that you require from the coring tools you use?

First, and most important, you require a core barrel which will bring to the surface a true core of the formation penetrated by the bit—unburned, undistorted, uncontaminated, undamaged in any way—from which you can accurately judge underground conditions.

When you use Baker Coring Equipment, that is exactly the type of core you will secure.

Second, and almost equally important, you want coring equipment which functions accurately and steadily, day after day, without exasperating and unnecessary delays.

Baker Core Barrels—both Cable Tool and Rotary—are noted for their efficiency in operation.

Their accuracy in performance and the perfection of the resultant cores are particularly valuable in exploration work, checking for favorable structures, the geologic column, porosity and saturation of the sands, and the various other factors of importance.

Guesswork and indecision are eliminated. Definitely dependable facts are placed in your hands by these two coring tools of superior performance ability.

You should have first-hand, complete information about the Baker Cable Tool Core Barrel and the Baker Rotary Core Barrel. It is yours for the asking. Write for it—today.

Export Sales Office:
Room 736, 25 Broadway,
New York, N. Y.

Stocks of Baker Tools and Equipment are carried by Dealers in all active fields

BAKER
OIL TOOLS, INC.

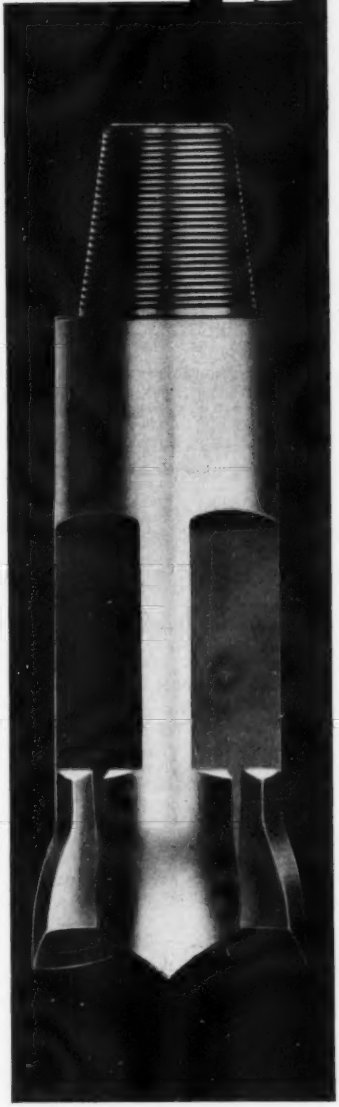
Main Office and Factory
Box L, HUNTINGTON PARK, CAL.

California Branches
Coalinga Taft Bakersfield

Mid-Continent Branches:
2301 Commerce St.
Houston, Texas
220 E. Brady St.
Tulsa, Okla.

Full Stocks and Immediate Service are always available

The MASTER CORE DRILL for CABLE TOOLS



The Elliott Cable Tool Core Drill makes cable tool coring as simple, easy, efficient, and dependable as coring with rotary tools.

It will make hole faster than a regular drilling bit. Operators can make as good time coring continuously with this tool as they can by alternating a regular cable tool bit with the average core drill.

Tell us your coring problems and we will send you complete information and performance records of the Elliott Cable Tool Core Drill especially adapted to your requirements; with advice and suggestions by experienced core drillers that will insure efficient, dependable results.

Elliott Cable Tool Core Drill, adapted to formations ranging from soft, sticky shale to hard conglomerate. Five types, for holes from 3 3/4" to 9 3/4" diameter. . . . (Larger sizes on special order only.)

Elliott
CORE DRILLING COMPANY
4731 East 52nd Drive
LOS ANGELES, CALIFORNIA.

Mailing Address: Box 55, Maywood, Calif.
Export Office: 150 Broadway, New York
Distributed exclusively in the United States east of the Rocky Mountains, by HINDERLITER TOOL COMPANY, of Tulsa, Oklahoma.

Leitz Petrological Microscope "CM"

LEITZ

Petrological (Polarising) Microscopes

OIL GEOLOGISTS

Only the most precise equipment will render dependable and unfailing results. ***The Leitz Petrological Microscopes meet the most exacting requirements for routine and research work, due to Superior Workmanship and Perfect Alignment.***

Leading Institutions, Government Departments, and Industrial Laboratories throughout the world recognize these indisputable features and have adopted Leitz Petrographical Microscopes as Standard for their Investigations.

Write for Catalog No. III-B (V)

E. LEITZ, Inc.
60 EAST 10th ST. NEW YORK

BRANCHES:
Washington, D. C. - Chicago, Illinois
Los Angeles, Calif. (Spindler & Sauppé, 811 West 7th St.)
San Francisco, Calif. (Spindler & Sauppé, 86 Third St.)

Verlag von Gebrüder Borntraeger in Berlin W 35 (Deutschland)

Erdöl. **Allgemeine Erdölgeologie und Überblick über die Geologie der Erdölfelder Europas** von **Dr. O. Stutzer,** o. ö. Professor für Brennstoffgeologie an der Bergakademie Freiberg (Sa.). Mit 199 Textabbildungen (XVI u. 628 S.) 1931
Gebunden, $15.

SPECIAL PRICE TO A. A. P. G. MEMBERS, $11.25

Verfasser, der viele Ölfelder kennengelernt hat, behandelt im vorliegenden Bande allgemeine Fragen der Erdölgeologie. Dann gibt er einen Überblick über die Erdöllagerstätten Europas einschleisslich Russlands. Das Buch ist für alle bestimmt, die für Erdöl Interesse haben und die umfangreiche Literatur nicht verfolgen können.

Ausführliche Verlagsverzeichnisse kostenfrei

An Amazing Underground Recording Job

by an ingenious instrument which enables well drillers and owners to conduct their activities with a true knowledge of actual conditions. A recording job that makes possible the elimination of crooked holes and their dire results.

If you're off the vertical the SYFO Clinograph will tell you accurately *how much*. It will tell you on paper—a permanent and easily read record. The SYFO makes unnecessary the use of dangerous acids.

The operation is speedy—the cost less than that of the acid bottle—the resulting information invaluable.

Write for literature and costs on this service.

Also makers of the SURWEL Clinograph, the gyroscopic surveying instrument that tells both the degree and direction of the deviation.

Sperry-Sun Well Surveying Company
1608 Walnut Street,
PHILADELPHIA, PA.

DALLAS, TEXAS
1501 Caruth Street
TULSA, OKLAHOMA
402 Petroleum Bldg.
HOUSTON, TEXAS
1417 Esperson Bldg.
LOS ANGELES, CALIF.
415 Petroleum Securities Bldg.
TYLER, TEXAS
Bell Bldg.
CALGARY, ALBERTA, CANADA
Room 1, Central Block

SYFO *Clinograph*

RECENT McGRAW-HILL BOOKS for Petroleum Geologists

Emmons' GEOLOGY OF PETROLEUM
New Second Edition

By William Harvey Emmons, Professor and Head of Department of Geology and Mineralogy, University of Minnesota; Director Minnesota Geological Survey. 736 pages, 6 x 9, 435 illustrations. **$6.00**

A complete, up-to-date reference work for the petroleum geologist, covering the geologic characteristics of oil fields, large and small, throughout the world. The book contains many new illustrations, index maps and cross sections.

Lahee's FIELD GEOLOGY
New Third Edition

By Frederic H. Lahee, Chief Geologist of the Sun Oil Company. 789 pages, 538 illustrations, pocket size, flexible **$5.00**

A thorough revision of this well-known manual of field geology, covering recent extensive advances in methods of geological exploration and mapping, particularly those that have been developed to meet the needs of the petroleum industry.

Ver Wiebe's OIL FIELDS IN THE UNITED STATES

By Walter A. Ver Wiebe, Professor of Geology, University of Wichita. 629 pages, 6 x 9, 230 illustrations. **$6.00**

A complete and systematic presentation of the fundamental facts of oil accumulation in all fields of the United States.

Examine these books for 10 days FREE
Send This Coupon

McGRAW-HILL FREE EXAMINATION COUPON

McGraw-Hill Book Company, Inc.,
370 Seventh Ave., New York City.

Send me the books checked below, postpaid, for ten days' free examination. I agree to pay for or return them within ten days of receipt.

Emmons—*Geology of Petroleum*, $6.00
Lahee—*Field Geology*, $5.00
Ver Wiebe—*Oil Fields in the United States*, $6.00

Signed.....
Address.....
City and State.....
Firm.....
Position..... P. G. 9-31

A Subscriber Writes:

"I wish to inform you that I find your journal full of most valuable information from start to finish and I am only sorry that I did not subscribe sooner."

You, too, will find much information of interest and value in

The OIL WEEKLY

If you read the "Office copy," why not have a copy sent to your home where you can read it at your leisure? The cost is only $1.00 a year. Use the attached order blank—NOW.

The OIL WEEKLY

P. O. BOX 1307 HOUSTON, TEXAS

Enter my name for one year's subscription to The OIL WEEKLY, for which you will find enclosed check for $1, as payment in full.

Name .....

Street and No. .....

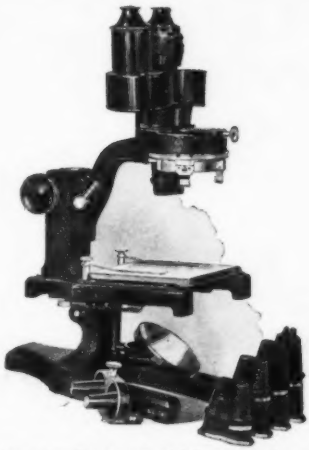
City and State .....

I am with The .....Company

and my position is .....

(BE SURE TO STATE COMPANY AND POSITION, otherwise it will be necessary for us to hold up entering your subscription until we can get this information from you.)

Please use coupon on last page of advertisements in answering advertisers



No. 55-as illustrated, with horseshoe base.
No. 56-the stage and body, base omitted.

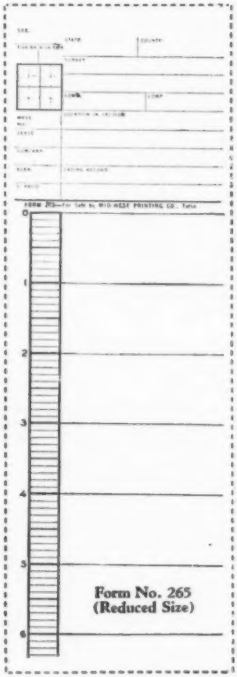
A Large Stage for Gross Specimens . . .

For the examination of large specimens, the Spencer Binocular Microscopes, Nos. 55 and 56, are equipped with a glass stage 100 mm x 100 mm square. Objects in the center of a dish 50 mm high and 130 mm in diameter may be brought into the lines of vision.

Thick, bulky specimens may be easily examined by virtue of the rack and pinion movement together with the adjustability of the arm on the slide, which enables the operator to increase the distance between the stage and objectives.

Folder M-47 describes the Spencer Nos. 55 and 56 Microscopes in detail. Write for it today.

Spencer Lens Company
BUFFALO NEW YORK

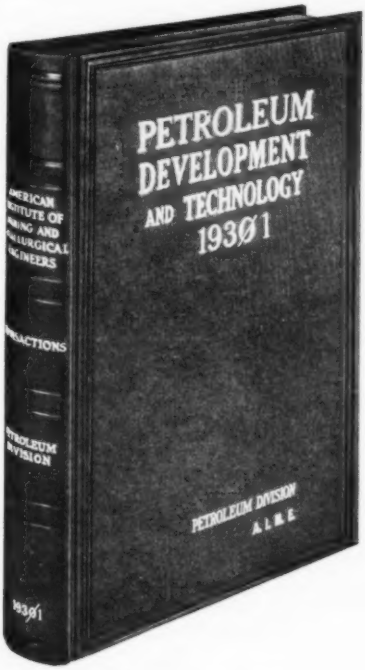


Form No. 265
(Reduced Size)

Well Logs

▲▲▲▲WE carry in stock, ready for immediate delivery, six different well logs printed on either heavy ledger paper or government post card stock, in depths ranging from 3,000 to 6,000 feet. ▲ Prices and samples of these logs sent on request.

MID-WEST PRINTING CO.
BOX 1465 TULSA, OKLA.
PRINTERS OF THE A. A. P. G. BULLETIN



The same friendly cover but entirely new contents fully maintaining the high standard of the Series!

Just off the press--

Transactions, Petroleum Development and Technology, 1931

65 papers 6 chapters 657 pages

Unit operation of oil pools; production engineering; engineering research; domestic and foreign production; economics; refining summary; the proceedings of the meetings of the Petroleum Division at Tulsa and Los Angeles, 1930, and New York, 1931.

Cloth bound, $5.00 to Non-members
Canadian and Foreign Postage $0.40 extra

Published by the
AMERICAN INSTITUTE OF MINING AND METALLURGICAL ENGINEERS
29 West 39th Street New York, N. Y.

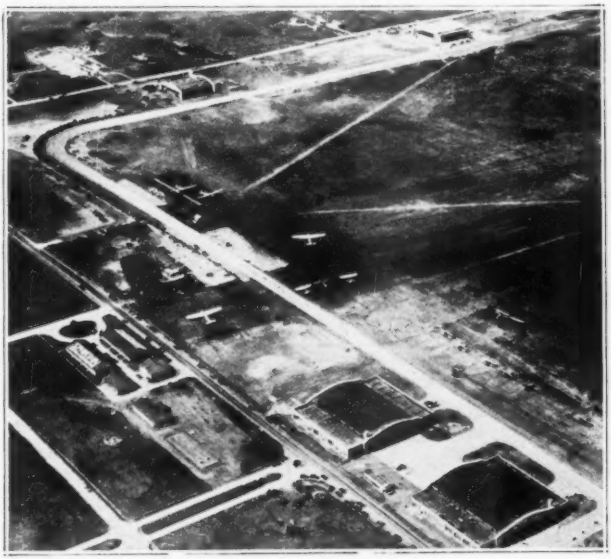
The Secretary, A.I.M.E.
29 West 39th St., New York, N. Y.
Please send me.....copies of Transactions, Petroleum Development and Technology, 1931. I enclose my check for $.....

Name.....

Street.....*City*.....

The Geologist's Time » »
« « is VALUABLE Time

▶When he is wanted, he is wanted in a hurry, and if he is not there he is holding up the works. SPEED COUNTS!



TULSA

The Oil Capital of the World, the home of the A.A.P.G. and of the International Petroleum Exposition, is also one of the world's

BEST KNOWN AIR CENTERS

This combination of attractions and advantages makes Tulsa the ideal place for the geologist to live and have his offices.

Write for descriptive literature to

TULSA CHAMBER OF COMMERCE
TULSA, OKLAHOMA

REVUE DE GÉOLOGIE
ET DES SCIENCES CONNEXES

Monthly review of geology and connected sciences under the auspices of

SOCIÉTÉ GÉOLOGIQUE DE BELGIQUE

with the collaboration of

The American Mineralogist, Société Géologique de France, Service Géologique de Pologne, Comitato della Rassegna di Geologia, Several Official Geological Surveys, Australian Science Abstracts, Bureau d'Histoire Naturelle de Prague, and numerous Geologists of all parts of the World.

GENERAL OFFICE of the "*Revue de Géologie*"
Institut de Géologie, Université de Liége, Belgique

TREASURER of the "*Revue de Géologie*"
35, Rue des Armuriers, Liége, Belgique

PRICES: Vol. I (1920) $10.00, Vol. II (1921) $8.00, Vol. III (1922) $7.50, Vol. IV (1923) $7.00, Vol. V (1924) $6.50, Vol. VI (1925) $6.00, Vol. VII (1926) $5.75, Vol. VIII (1927) $5.50, Vol. IX (1928) $5.25, Vol. X (1929) $5.25, Vol. XI (1930) $5.00 (subscription price). Moderate extra rate for cover if wanted.

SAMPLE COPY SENT ON REQUEST

A New Book

Physiography of Western United States

By

NEVIN M. FENNEMAN
Professor of Geology
University of Cincinnati

The purpose of this book is to summarize the present knowledge of the physiography of western United States, describing the land forms and giving their history.

xiii + 534 pages, 6 × 9 inches, 174 illustrations, cloth.

PRICE, $5.00

Order from

The American Association of Petroleum Geologists

Box 1852 **Tulsa, Oklahoma**

Speed- Simplicity- Sensitivity

THE
HOTCHKISS SUPERDIP
For Magnetic Exploration

W. C. McBRIDE, INC.
704 Shell Bldg., St. Louis, Mo.

Geological and geomagnetic surveys conducted under the direction of DR. NOEL H. STEARN.

Minnesota Representative—HOLMAN I. PEARL, First National Bank Bldg., Crosby, Minnesota
West Coast Representative—ELMER W. ELLSWORTH, P. O. Box 658, Stanford University, California

The Annotated
Bibliography of Economic Geology
Vol. III, No. 1
is now being mailed

Orders are now being taken for the entire volume at $5.00 or for individual numbers at $3.00 each. Volumes I and II can still be obtained at $5.00 each.

The number of entries in Vol. I is 1756. Vol. II contains 2480. Vol. III will contain 2400. If you wish future numbers sent you promptly, kindly give us a *continuing* order.

Economic Geology Publishing Co.
Urbana, Illinois, U. S. A.

Dear Sirs:

Please send Vol. I, Vol. II, Vol. III, etc. of the Annotated Bibliography of Economic Geology to me at the following address.

Enclosed find.....in payment therefor.

Name.....

Address.....

Country.....

Date.....

Please use coupon on last page of advertisements in answering advertisers

BULLETIN
of the
AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

F. H. LAHEE, *Third Vice-President in Charge of Editorial Work*
J. P. D. HULL, *Acting Editor*

REGIONAL ASSOCIATE EDITORS

GENERAL—
Geology: K. C. HEALD, The Gulf Companies, Frick Building Annex, Pittsburgh, Pennsylvania
Geophysics: B. B. WEATHERBY, Geophysical Research Corporation, Box 2022, Tulsa, Oklahoma

UNITED STATES—
Appalachian and Eastern: W. A. THOMAS, The Pure Oil Company, 402 Second National Bank Building, Saginaw, Michigan
HUGH D. MISER, U. S. Geological Survey, Washington, D. C.
North Mid-Continent: ANTHONY FOLGER, Gypsy Oil Company, Box 1144, Wichita, Kansas
THERON WASSON, Room 2308, 35 E. Wacker Drive, Chicago, Illinois
Central Mid-Continent: FRANK C. GREENE, 1434 South Cincinnati Avenue, Tulsa, Oklahoma
ROBERT H. DOTT, 1521 South Yorktown Avenue, Tulsa, Oklahoma
South Mid-Continent:
Western R. E. RETTGER, Sun Oil Company, San Angelo, Texas
M. G. CHENEY, Coleman, Texas
Eastern W. C. SPOONER, Box 1195, Shreveport, Louisiana
Gulf Coast: DONALD C. BARTON, Petroleum Building, Houston, Texas
W. ARMSTRONG PRICE, Box 112, Corpus Christi, Texas
Rocky Mountains: R. CLARE COFFIN, 931 First National Bank Building, Denver, Colorado
Pacific Coast: W. S. W. KEW, Standard Oil Company, 524 Standard Oil Building, Los Angeles, California
STANLEY C. HEROLD, 756 South Broadway, Los Angeles, California

FOREIGN COUNTRIES—
General: W. B. HEROY, Room 1500, 45 Nassau Street, New York City
Canada: B. F. HAKE, Nordon Corp., Ltd., 515 Lougheed Building, Calgary, Alberta
Europe and Mediterranean: W. P. HAYNES, 82 Avenue des Champs Elysees, Paris, France

THE BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS is published by the Association on the 15th of each month. Editorial and publication office, 505 Tulsa Building, Tulsa, Oklahoma, Post Office Box 1852. Cable address, AAPGEOL.

THE SUBSCRIPTION PRICE to non-members of the Association is $15.00 per year (separate numbers $1.50) prepaid to addresses in the United States. For addresses outside the United States, an additional charge of $0.40 is made on each subscription to cover extra wrapping and handling.

British agent: Thomas Murby & Co., 1 Fleet Lane, Ludgate Circus, London, E. C. 4.

German agent: Max Weg, Königstrasse 3, Leipzig, Germany.

CLAIMS FOR NON-RECEIPT of preceding numbers of the BULLETIN must be sent to the business manager within three months of the date of publication in order to be filled gratis.

BACK NUMBERS of the BULLETIN, as available, can be ordered from Association headquarters. Cloth-bound Vol. 2 (1918), $4.00; Vol. 3 (1919), $5.00; Vol. 5 (1921), $12.00; Vols. 11 (1927), 12 (1928), 13 (1929), 14 (1930), each $17.00. Other volumes, many separate numbers, and a few nearly complete sets are available. Descriptive price list sent on request. Special prices to members and associates. Discounts to libraries. Detailed *10-Volume Index* (1917-1926), $1.00. *Theory of Continental Drift* (1928), $5.00. *Structure of Typical American Oil Fields*, Vol. I (1929), $5.00; Vol. II (1929), $6.00; each volume $4.00 to members and associates; after January 1, 1932, each volume $7.00 ($5.00 to members and associates).

THE BULLETIN furnishes thirty-five free reprints of major papers. Additional reprints and covers for all or part, are furnished at cost. ORDERS FOR REPRINTS should accompany corrected galley proof.

Association Headquarters—505 Tulsa Building, East Fifth Street at Cincinnati Avenue, Tulsa, Oklahoma.

Communications about the Bulletin, manuscripts, editorial matters, subscriptions, special rates to public and university libraries, publications, membership, change of address, advertising rates, and other Association business should be addressed to

J. P. D. HULL, *Business Manager*
THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS, INC.
BOX 1852
TULSA, OKLAHOMA

Entered as second-class matter at the Post Office of Tulsa, Okla., under the Act of March 3, 1879. Acceptance for mailing at special rate of postage provided for in section 1103, Act of October 3, 1917, authorized March 9, 1923.

MID-WEST PRINTING CO., TULSA, OKLA., U. S. A.

Please use coupon on last page of advertisements in answering advertisers

THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS, INC.

OFFICERS FOR THE YEAR ENDING MARCH, 1932

LOVIC P. GARRETT, *President*
Houston, Texas

SIDNEY POWERS, *Past-President*
Tulsa, Oklahoma

L. COURTNEY DECIUS, *First Vice-President*
San Francisco, California

FRANK RINKER CLARK, *Second Vice-President in Charge of Finances*, Tulsa, Oklahoma

FREDERIC H. LAHEE, *Third Vice-President in Charge of Editorial Work*, Dallas, Texas

DISTRICT REPRESENTATIVES

(Representatives' terms expire immediately after annual meetings of the years shown in parentheses.)

Amarillo:
Victor Cotner (1932), Amarillo, Tex.

Appalachian:
Leon J. Pepperberg (1933), Columbus, Ohio

Canada:
Theodore A. Link (1933), Calgary, Canada

Capital:
H. D. Miser (1932), Washington, D. C.

Dallas:
Willis Storm (1932), Dallas, Tex.

East Oklahoma:
John M. Nisbet, (1932), Bartlesville, Okla.
W. R. Hamilton (1933), Tulsa, Okla.
R. S. Knappen (1933), Tulsa, Okla.

Fort Worth:
H. B. Fuqua (1933), Fort Worth, Tex.

Great Lakes:
Theron Wasson (1933), Chicago, Ill.

Houston:
John F. Weinzierl (1933), Houston, Tex.

Mexico:
S. A. Grogan (1933), Tampico, Mexico

New Mexico:
R. K. DeFord (1933), Roswell, New Mexico

New York:
H. J. Wasson (1933), New York, N. Y.

Pacific Coast:
Harry R. Johnson (1933), Los Angeles, Calif.
C. R. McCollom (1932) Los Angeles, Calif.
R. D. Reed (1933), Los Angeles, Calif.

Rocky Mountains:
R. Clare Coffin (1933), Denver, Colo.

San Antonio:
Ed. W. Owen (1933), San Antonio, Tex.

Shreveport:
S. C. Stathers (1933), Shreveport, La.

South America:
C. A. Baird (1933), Maracaibo, Venezuela, S. A.

Southern Permian Basin:
Joseph E. Morero (1933), Midland, Tex.

West Oklahoma:
A. H. Richards (1933), Oklahoma City, Okla.

Wichita:
L. W. Kesler (1933), Wichita, Kan.

Wichita Falls:
J. P. Bowen (1932), Wichita Falls, Tex.

DIVISION REPRESENTATIVES

Division of Paleontology and Mineralogy:
R. C. Moore (1932), Lawrence, Kan.
Gayle Scott (1932), Fort Worth, Tex.

PACIFIC SECTION

(Chartered, March, 1925)

M. G. EDWARDS, *President*, 433 Higgins Building, Los Angeles, California
L. N. WATERFALL, *Secretary-Treasurer*, 1114 Union Oil Building, Los Angeles, California

Membership is restricted to members of the A.A.P.G. in good standing, residing in the Pacific Coast states. Dues of $2.00 per year are payable to the secretary-treasurer of the Pacific Coast Section. Members of the A.A.P.G. transferring to the Pacific Coast are cordially invited to become affiliated with the local section, and to communicate their change of address promptly to the secretary-treasurer of the Pacific Section.

SAN ANTONIO SECTION

(Chartered, April, 1929)

HERSCHEL H. COOPER, *President*, 1642 Milam Building, San Antonio, Texas
J. D. HEDLEY, *Secretary-Treasurer*, 1014 Milam Building, San Antonio, Texas

Membership is limited to persons who are eligible to membership in The American Association of Petroleum Geologists. Annual dues: $2.50. Annual meeting: the last Friday in February.

MARACAIBO SECTION

(Chartered, April, 1930)

WILLIAM H. SPICE, JR., *President*, Lago Petroleum Corporation, Maracaibo, Venezuela
CHESTER A. BAIRD, *Secretary-Treasurer*, Venezuela Gulf Oil Company, Maracaibo, Venezuela

DIVISION OF PALEONTOLOGY AND MINERALOGY

SOCIETY OF ECONOMIC PALEONTOLOGISTS AND MINERALOGISTS

(Affiliated, March, 1928; chartered, technical division, April, 1930)

CHARLES E. DECKER, *President*, Norman, Oklahoma
GAYLE SCOTT, *Secretary-Treasurer*, Texas Christian University, Fort Worth, Texas

The Society issues a quarterly, the *Journal of Paleontology*, Raymond C. Moore, editor, University of Kansas, Lawrence, Kansas: subscription, $6.00. Society dues (including subscription to *Journal*), $6.00. A remission of $2.00 is allowed on dues of members who are also members or associate members of the Association. Therefore, members or associate members of the Association in good standing who are engaged in stratigraphic studies as applied to petroleum geology are eligible to membership in the society, and may receive the *Journal of Paleontology* for $4.00 in addition to their Association dues. Membership application forms and back numbers of the *Journal* may be obtained from Association Headquarters, Box 1852, Tulsa, Oklahoma.

Please use coupon on last page of advertisements in answering advertisers

BULLETIN

of the

AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

Volume 15 **SEPTEMBER 1931** **Number 9**

CONTENTS

PERMO-CARBONIFEROUS OROGENY IN SOUTH-CENTRAL UNITED STATES . . 991
By W. A. J. M. van Waterschoot van der Gracht

PRE-CARBONIFEROUS STRATIGRAPHY OF MARATHON UPLIFT, WEST TEXAS . 1059
By Philip B. King

DETAILED CROSS SECTION FROM YATES AREA, PECOS COUNTY, TEXAS, INTO SOUTHEASTERN NEW MEXICO 1087
By H. P. Bybee, E. F. Boehms, Cary P. Butcher, H. A. Hemphill and G. E. Green

GEOLOGICAL NOTES

Supposed Marine Jurassic (Sundance) in Foothills of Front Range of Colorado, *John B. Reeside, Jr.* 1095

Silicified Shell Fragments as an Indication of Unconformity, *J. V. Howell* 1103

DISCUSSION

Bearing of Cap Rock on Subsidence on Clay Creek Salt Dome, Washington County, Texas, and Chestnut Dome, Natchitoches Parish, Louisiana, *Marcus I. Goldman* . . . 1105

Clay Creek Salt Dome, Washington County, Texas, *Frederic H. Lahee* 1113

REVIEWS AND NEW PUBLICATIONS

Physics of the Earth—II. The Figure of the Earth, *National Academy of Sciences* (B. B. Weatherby) 1117

Recent Publications 1118

THE ASSOCIATION ROUND TABLE

Supplementary Membership List 1119

AT HOME AND ABROAD

Current News and Personal Items of the Profession 1121

Articles Scheduled for Publication in the October *Bulletin*

Donaldson Bogart Dowling Memorial Symposium on Stratigraphy of Plains of Southern Alberta

STRATIGRAPHIC CORRELATION AND NOMENCLATURE IN PLAINS OF SOUTHERN ALBERTA
By J. S. IRWIN

PALEOZOIC OF SOUTHERN PLAINS OF ALBERTA
By P. D. MOORE

ELLIS (UPPER JURASSIC) SECTION AT EAST BUTTE, SWEET GRASS HILLS, MONTANA
By J. O. G. SANDERSON

STRATIGRAPHY OF RED COULEE FIELD
By W. S. YARWOOD

STRATIGRAPHY OF COLORADO SHALE IN SOUTHERN PLAINS OF ALBERTA
By J. G. SPRATT

STRATIGRAPHY OF FOREMOST, PAKOWKI, AND MILK RIVER FORMATIONS OF SOUTHERN PLAINS OF ALBERTA
By S. E. SLIPPER and H. M. HUNTER

SUBSURFACE STUDY OF PALE BEDS AND FOREMOST FORMATION IN LETHBRIDGE-BROOKS AREA OF SOUTHERN ALBERTA
By DELMER L. POWERS

SEDIMENTS OF MONTANA AGE IN MILK RIVER RIDGE REGION, ALBERTA
By B. F. HAKE and CARL C. ADDISON

BEARPAW SHALE AND CONTIGUOUS FORMATIONS IN LETHBRIDGE AREA, ALBERTA
By THEODORE A. LINK and A. J. CHILDERHOSE

SECTIONS OF BEARPAW SHALE FROM KEHO LAKE TO BASSANO, SOUTHERN ALBERTA
By CLARE M. CLARK

FOX HILLS FORMATION IN SOUTHERN ALBERTA
By J. O. G. SANDERSON

STRATIGRAPHY OF SPRING COULEE WELL
By W. S. YARWOOD

STRATIGRAPHY OF SPRING COULEE WELL. Supplementary paper.
By W. P. MELLEN and F. W. ROHWER

INVERTEBRATE PALEONTOLOGY OF SOUTHERN PLAINS OF ALBERTA
By P. S. WARREN

Volume 15 Number 9

BULLETIN

of the

AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

SEPTEMBER 1931

PERMO-CARBONIFEROUS OROGENY IN SOUTH-CENTRAL UNITED STATES[1]

W. A. J. M. VAN WATERSCHOOT VAN DER GRACHT[2]
Feldbach, Styria, Austria

ABSTRACT

This paper is a synopsis of the late Paleozoic orogeny in the south-central states of North America. Recent papers by American geologists and personal work of the writer and his collaborators are coördinated into as complete a treatise as present knowledge permits.

Two independent mountain systems, the Wichita and the Ouachita, are distinguished. The Wichita system comprises the Wichita Mountains, the Criner Hills, the Arbuckle Mountains, the buried folds along Red River including the Muenster arch, and the buried Amarillo Mountains. These folds, though belonging to the Permo-Carboniferous phase, originated within an *intra-continental* pre-Middle Devonian geosyncline, in which the major accumulation of predominantly marine limestone sediments was pre-Devonian. This system strikes generally west and west-northwest. It meets nearly at right angles the front of the second complex, the considerably more important Ouachita system.

The Ouachita system (in a wider sense) is a large arcuate feature of which only a small part of the widely overthrust outer rim of the northernmost loop is exposed in the Ouachita Mountains of southeastern Oklahoma and Arkansas. Most of this system is buried, though folds exposed in the Marathon uplift belong to the southwestern extension of the same system, which, as the writer believes, in Oklahoma and Arkansas is itself an extension of the Appalachians, which disappear in Alabama under the Cretaceous blanket of the Gulf Coastal Plain.

Unlike the Wichita complex, the Ouachita ranges originate from an *inter-continental* Carboniferous geosyncline, with major post-Devonian deposition, principally in the latest Mississippian or earliest Pennsylvanian. The facies of the rocks is also intrinsically different. The exposed part consists of great overthrust masses, of a structural type that can best be compared with the northern front of the European Variscan system in France and Belgium.

The principal phases of folding in both the Wichita and the Ouachita systems are Pennsylvanian; the final phase of the overthrusting of the Ouachitas is possibly Permian. Precursory Mississippian and older movements are indicated.

[1]Read in abstract before the Association at the New Orleans meeting, March 22, 1930; also briefly presented at the meeting of the Royal Academy of Sciences in Amsterdam, February, 1930. Manuscript received, January 5, 1931.

[2]Hainfeld Castle.

Recent geological subsurface work makes possible the tracing of the rim of the buried Ouachita front range through east-central Texas, first by the characteristic, depressed early Pennsylvanian foreland basin, which exactly reproduces the coal basin foredeep of southeastern Oklahoma and southern Arkansas, and then by wells which actually have penetrated to the mountain front.

The present Llano-Burnet uplift marks the existence of a resistant buttress in the foreland, causing a salient around which the chains turn, to reassume a southwest course in southwestern Texas and northern Mexico; here the folds reappear at Marathon, beyond which they disappear beneath the Cordillera in Mexico.

The Hunton arch is another important buttress, causing the uplift of the folded foreland fault-slices of the Arbuckle Mountains.

The character of the nappe (overthrust) structure of the Ouachita chains is discussed and compared with the very similar build of European mountain chains. These mountains are not merely the edge of an ancient "Llanoria," but a great range of world-wide importance.

INTRODUCTION[1]

The region under discussion in this paper is bordered on the west by the eastern edge of the Rocky Mountain system, on the south by the Rio Grande and the Gulf of Mexico, on the east by Mississippi River, and on the north by the northern state lines of Kansas and Arkansas (Fig. 1). It comprises the southwestern spur of the Laurentian nucleus of the North American continent, its covering of Paleozoic plateau deposits, and its rim of late Paleozoic mountains.

The Paleozoic geology and paleogeography of the region are entirely controlled by a system of mountains which originated in the great world-wide Permo-Carboniferous orogenic cycle. These chains evidently control the sedimentation and structure of the region and thereby the consequent accumulation of petroleum. Not only is this true for the Paleozoic oil reservoirs, but it is probable that many of the important oil fields of the southern states, which occur in younger strata, ranging from the late Permian to the younger Tertiary, are structurally as well as genetically influenced by the general plan, and possibly, in some places, by petroliferous strata of the Paleozoic basement.

Our subject is one of particular difficulty, because, to a far greater extent than the Permo-Carboniferous structures of Eurasia, the old

[1]The writer wishes to express his thanks to the geologists who collaborated with him in the investigations which he has organized and directed, and have assisted him in this research. In addition he received much information and assistance from the friendly intercourse and correspondence of many geologists. Many papers dealing with the subject are cited in the attached bibliography.—W. A. J. M. van der Gracht.

The original manuscript for this paper was revised by the editor with the assistance of the following geologists: C. L. Baker, C. L. Dake, B. H. Harlton, F. A. Bush, J. A. Waters, and Sidney Powers. A great many of the facts incorporated in the paper have been published previously or were made available by the geologists whose names are listed. To each of these gentlemen is due much credit for thoughtful suggestions and constructive criticism which have enabled the author to bring the text up to date.—F. H. Lahee, editor.

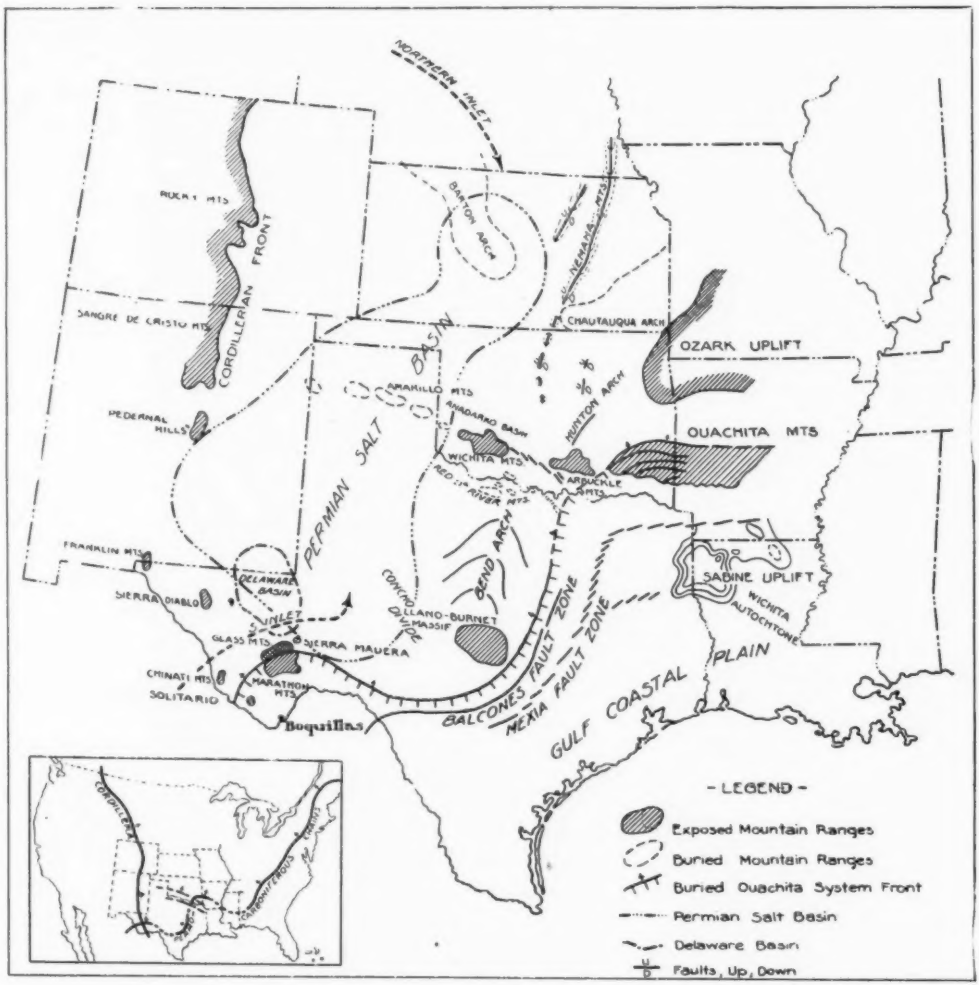


FIG. 1.—Late Paleozoic tectonic features in south-central United States. Width of area shown in map, approximately 1,400 miles. Redrawn and revised by Sidney Powers.

mountains are almost completely buried under a great thickness of more recent, chiefly Cretaceous sediments. In the Gulf Coastal Plain these grade upward into a great mass of Tertiary. Even within much of the plateau region, a thick blanket of Permian deposits, laid down after the major diastrophism, obscures the old folds. Only in a few, very restricted areas are fragments of the old structures exposed: the Ouachita Mountains of Arkansas and southeastern Oklahoma, and the Arbuckle Mountains and the Wichita Mountains of southwestern Oklahoma. These conspicuous islands of Paleozoic and older rocks, with their intense folding and faulting, have attracted the attention of geologists from the very first moment that this region began to be scientifically explored. The general late Paleozoic age of the diastrophism was soon established. It was difficult, however, to correlate the isolated outcrops, which present disconcerting differences in facies of the rocks as well as in structure. The same applies to another isolated exposure of Paleozoic folds, considerably farther southwest, in the uplifts of Marathon and Solitario, in the midst of the Cretaceous cover. It will be seen that a similar uplift of Paleozoic and pre-Cambrian rocks in the Llano-Burnet region of central Texas is no part of the mountains, but a foreland massif.

Only through extensive exploration for petroleum has sufficient knowledge of the older Paleozoic floor been obtained to make possible a more regional analysis of the fundamental structure of this entire region. Very valuable information has recently been obtained and published in papers by various workers, many of them petroleum geologists, who have collected and discussed the results of the intense drilling campaign of the last ten years. The writer cites in particular papers by Luther H. White (**61**, 1926), Robert H. Dott (**21**, 1927), C. W. Honess (**28**, 1927), Sidney Powers (**49**, 1928), H. D. Miser (**45**, 1927, **44**, **46**, 1929), M. G. Cheney (**14**, **15**, 1929), C. W. Tomlinson (**54**, 1929), C. M. Becker (**6**, 1930), F. A. Melton (**41**, 1930), P. B. and R. E. King (**36**, 1930), and many others listed in the attached bibliography.[1] They offer a valuable symposium of present knowledge of facts.

In the present treatise the writer critically discusses and correlates this material further, attempting to give a comprehensive picture of the general structure of the mountain chains encircling this important region, and to offer a theory which has gradually grown in his conviction and has been considerably strengthened by the data, observations, and thoughts of the authors mentioned. For much detail the reader must be referred to the original papers and to the writer's more extensive mono-

[1]Numbers in bold face type refer to the appended bibliography.

graph (in the English language) published in the Transactions of the Royal Academy of Amsterdam.[1]

In addition to the Ouachita, Arbuckle, and Wichita mountains, and the exposures at Marathon and Solitario, the drill has revealed several other buried structures which clearly belong to the same system of mountain chains. They constitute similar fault blocks, which fail to protrude through the covering blanket.

In the western prolongation of the Wichita Mountains, a row of great buried peaks of granite has been outlined by drilling in northern Texas, extending into eastern New Mexico. These are the Amarillo Mountains, famous for the oil and gas accumulations which are associated with the Texas Panhandle.

South of the exposures of the Wichita Mountains and the Arbuckle Mountains, a wide zone of buried *échelon* folds has been revealed all along Red River, in the border region between Oklahoma and Texas. The ridges are associated with deep depressions, evidently great synclinoria belonging to the same system. The Criner Hills, just south of the Arbuckle Mountains, form a small isolated surface exposure of these southern structures in the form of a fault block; all the others are buried. The anticlines cause many well known oil fields. This entire region evidently belongs to the same general zone of folding as the exposed part of the Wichita chain, and contains the same sequence and facies of sediments.

The pre-Cambrian basement of the southern region of the Mid-Continent plateau consists of a thoroughly base-leveled floor of gneisses, schists, some crystalline limestones, and other metamorphic sedimentary rocks, with intrusions of granite and other plutonic rocks.

Some probably very ancient positive elements are in evidence in this basement.[2] These influence the structure as well as late sedimentation in their vicinity. Among these, the Ozark dome, the Nemaha Granite ridge of Kansas and Oklahoma, the Hunton arch of southeastern Oklahoma, and the Concho divide or axis of south-central Texas (to which seemingly belongs the outcropping Llano-Burnet uplift) are particularly prominent.

Two general strikes are suggested as representing trends in the old basement. The most prominent, most clearly developed in Oklahoma and Kansas, is generally north and south, with deflections north-north-

[1] *Afdeeling Natuurkunde* (Royal Acad. Sci.) *Proc.*, Sec. II, Vol. 27, No. 3 (1931).

[2] R. Ruedemann, "Fundamental Lines of North American Geologic Structure," *New York State Mus. Bull. 260* (1924).

east and north-northwest. Another, northwest and southeast, is more in evidence in Texas in the old rocks of the Llano-Burnet uplift and in the Concho divide. This may be reflected in similar directions farther north in the area of the Salina basin of western Kansas. These two trends may reflect the old grain of Laurentia, which thereby continues to influence part of the Paleozoic deformation.

The most notable representative of the presumably pre-Cambrian substructure of Kansas is the Nemaha ridge, which seems to the writer to be an uplifted tilted fault block in the old floor, with a downthrown scarp on its eastern side. Paralleling the Nemaha ridge in Kansas, and near the Oklahoma state line, is a series of similarly shaped and similarly trending minor features, more or less *en échelon*. These have in all probability an analogous deep-seated origin and also reflect fault blocks in the basement floor. Nearly all these form more or less north-south trending asymmetric anticlines, overlying tilted fault blocks, with either a fault or a steep flexure, mainly on their eastern side.

Another ancient feature, with the same general trend and almost certainly originating in the pre-Cambrian floor, is the Hunton arch (or axis). It evidently extends through and beyond the Arbuckle uplift. This ancient positive element must be considered as antedating the geosyncline from which the Wichita complex of mountains originated. It probably caused the present Arbuckle Mountains and the Criner Hills south of them to stand out again as uplifts exposing the old mountain structure. In middle Pennsylvanian time it caused the region of the Arbuckles to protrude from the otherwise depressed foreland and to remain subject to erosion.

The Cushing structure belongs to a similar feature.

On the west the region is bordered by the great uplifted front scarp of the Rocky Mountains and Sangre de Cristo range, which seem to represent the front of a true crustal thrust block (basement thrust, *charriage à sec*) in the sense of Argand. These ranges were initiated at least as early as late Pennsylvanian time, but they did not assume their present form until the time *between* late Cretaceous and late Tertiary. A pre-Cambrian origin is suggested, but not proved.

The pre-Cambrian basement received a blanket of sediments extending from the Cambrian until the close of Hunton time (Lower Devonian). This sedimentation gradually buried the old hills, notably the Nemaha ridge. This was succeeded by a period of emergence, during which the region was slightly tilted west-southwest, away from the Ozark doming, and eroded to a peneplain, in which all the formations

from early Ordovician to Lower Devonian, inclusive, are exposed in a very persistent facies, now forming broad belts with a general west-northwest strike (**61**). Submergence and deposition followed again in the Chattanooga period, depositing sediments unconformably overlying the old peneplain. These contain the limestones, calcareous shales, and shales of the "Mississippi lime."

All these structures were considerably folded, faulted, and uplifted, and thereafter eroded in post-Mississippian-pre-Cherokee time, indicating an early Carboniferous orogenic phase affecting this entire plateau area. A later submergence covered the area with a blanket of late Lower Pennsylvanian (Cherokee) sediments. This period of deposition continued until well into the Permian (**1**, **16**, **39**, **40**).

During the entire Pennsylvanian and much of the Permian, orogeny was active along the southern border of the old plateau. Much of the area was somewhat rejuvenated in Tertiary and probably still more recent time, when the whole of the earth's crust became subject again to shearing and warping, culminating in the world-wide Alpine orogeny.

TWO PALEOZOIC GEOSYNCLINES

Two distinct geosynclinal troughs control the paleogeographic distribution, as well as the tectonic structure, of the Paleozoic sediments which were laid down over the pre-Cambrian basement in this region. These are (1) a pre-Middle Devonian geosyncline, trending west-northwest and east-southeast (a pre-Cambrian direction?) through southern Oklahoma and northern Texas, a belt now occupied by the Wichita-Arbuckle-Red River mountains; and (2) a considerably more important Carboniferous geosyncline which bordered the plateau region beyond its southern rim.

The first pre-Middle Devonian geosyncline is intra-continental, situated still within the plateau, at least its known part in Texas and Oklahoma, as the plateau region continues south of it in central Texas. In it accumulated a great thickness (9,000 feet) of Cambro-Ordovician, Silurian, and Lower Devonian sediments, largely in massive marine limestone facies. These same old Paleozoic sediments cover this entire area of the plateau,[1] but here they represent only an aggregate thickness of 1,000-1,500 feet, thinning toward the north and west, with the exclusion of the Salina basin of Kansas. The massive Arbuckle limestone is the most prominent feature. This member of the Cambro-Ordovician

[1]On the broad Ozark uplift they have been partly eroded, and some of them may not have been deposited (Luther H. White, **61**).

alone reaches a thickness ranging from 4,000 to 6,000 feet in the Wichita-Arbuckle geosyncline, compared with 800-1,000 feet in the equivalent "Siliceous limestone" of Oklahoma and Kansas, which thins toward the north. The Ellenburger limestone of Texas, south of the geosyncline, with a thickness of at least 1,000 feet, belongs to the same facies of the Lower Ordovician. This geosynclinal, but nevertheless epeiric, development of the Cambro-Ordovician, Silurian, and Devonian is succeeded by approximately 1,500 feet of Mississippian rocks: Woodford chert, Sycamore limestone, and the lower part of the Caney shale, in a similar facies, and these, in turn, by Lower Pennsylvanian rocks.

The second (Carboniferous) geosyncline has the characteristics of an *outer inter-continental geosyncline*, very different from the development in the Wichita intra-continental trough. Here no abnormal thickness of pre-Devonian sediments is in evidence and the facies is totally different from that of these strata on the plateau or in the Wichita geosyncline. The Ordovician-Devonian series is no longer developed as a massive limestone sequence, but as approximately 3,000 feet of cherts, graptolite-bearing siliceous shales, and some fine-grained quartzitic sandstones. It is only in the upper part of the Lower Carboniferous that geosynclinal conditions become very pronounced, causing accumulation of the enormous thickness of 17,000 - 20,000 feet of Stanley-Jackfork (Mississippian-Pennsylvanian) sediments, not represented in the Arbuckle Mountains. The clastic Stanley-Jackfork sediments of the Ouachita Mountains are comparable, in their broader structural relations, with the flysch facies of Europe.[1] They must be considered an orogenic

[1]The *Alpine Flysch* is a sequence of sediments deposited during the later stages (Cretaceous to Oligocene) of the geosyncline, directly previous to the major paroxysm, when initial diastrophism had already developed interior ridges exposed to erosion. In the locally shallow, but elsewhere possibly very deep, troughs of this early structure, a very characteristic marine sequence, composed chiefly of clayey muds, with more or less sandy beds intercalated in the shales, were laid down to a great thickness. This formation can be conceived as rapidly filling the foredeep, which was being depressed in front of an advancing major crustal thrust block and migrating with it.

Since this Flysch type of deposit is not confined to the Alps and the Carpathians, but is found characteristically associated with all folded-mountain systems of Alpine structure, the term "flysch" is used to denote this particular orogenic sedimentary *facies*, anywhere in the world, regardless of its age and the location where it occurs.

The *Molasse* in the Alps is a generally much more clastic, very thick sequence, succeeding the Flysch; partly marine, partly deltaic, in many places containing enormous masses of coarse conglomerates. It is the detritus worn from elevated ranges during and immediately after the major diastrophism, deposited in the later foredeep, considerably in front of the preceding Flysch geosyncline. It may be deformed and overthrust by the final last advance of the nappes (overthrust sheets; see footnote, pp. 1000-01).

As this is also a typical formation common to all large mountain chains, the term "molasse" may be applied to all orogenic deposits of a similar genesis.

Consequently, in this paper frequent reference is made to the flysch and molasse deposits of the Paleozoic American mountains, which we are discussing.

deposit. They are not represented on the foreland plateau. The Middle and Lower Mississippian predominantly limestone deposits of the foreland are absent in the Carboniferous geosyncline, or, possibly, are represented by the upper part of the cherts of the novaculite sequence.

DIASTROPHISM: TWO DISTINCT MOUNTAIN SYSTEMS

The first pre-Carboniferous geosyncline, previously described, was in early Pennsylvanian time compressed into the west-northwest and east-southeast fault blocks and folds of the Wichita Mountains, the Criner Hills, the *échelon* folds of the Red River and Muenster arches, and finally, in a later Pennsylvanian and Permian phase, in the Arbuckle Mountains. The buried Amarillo Mountains belong to the same orogeny. This complex of related chains may be designated the Wichita system for the purpose of this paper.

The second and far more important geosyncline was compressed into the quite distinct Ouachita system. Only a small part of the outer overthrust rim of this certainly superior mountain complex has remained exposed in southeastern Oklahoma and western Arkansas. Everything else has subsided and now lies deeply buried. This great arcuate chain of the Ouachita Mountains has been strongly pushed toward the northwest. The Oklahoma-Arkansas Ouachitas must be considered as lying considerably farther north than the original geosyncline in which these rocks were deposited. They have, in the writer's opinion, been pushed far out over their foreland. The originally very wide geosynclinal area, whence they came, may have been located south of the Sabine uplift in northern Louisiana and must have extended under the region now occupied by the Gulf of Mexico and its coastal plain.

For the purpose of this paper, the writer refers to all the mountains issuing from this outer geosyncline as the Ouachita Mountain system in its wider sense.

Both the Wichita and Ouachita mountain systems, regardless of the different age of their geosynclines, belong essentially to the Permo-Carboniferous phase of orogeny; both are the result of a general geotic creep (relatively) toward the north. In the Ouachita chains, which are strongly arcuate, the movement is generally directed toward the northwest, and diverges toward the west in those parts of the loop which trend more or less north and south in eastern Texas. The writer believes that the frontal chains continue throughout eastern Texas, sweeping around the Llano-Burnet massif, and reappearing at Marathon and in the Solitario uplift, beyond which we lose them under the folds of the Cordillera

in the unexplored mountain wilderness of Chihuahua in Mexico. Thus the Ouachita system is thought to encircle the entire southeastern side of the Laurentian mass.

The writer's idea regarding the relation between the Wichita and the Ouachita mountain systems is the following. The Wichita system trends at right angles to the western wing of the Ouachita loop in Atoka and Bryan counties, Oklahoma, and, in the writer's opinion, *passes underneath it*. The far more important Ouachita Mountains have been thrust toward the northwest and west in a series of overthrust sheets over the antedating Wichita system, which continues in the autochtone for an unknown distance toward the southeast. Possibly, though as yet there is no means of knowing, the conspicuous positive element of the Sabine uplift, which lies exactly in the trend of the Wichita chains, may be connected with these.

SEDIMENTARY SEQUENCE IN THE TWO GEOSYNCLINES

The dissimilarity between the two sedimentary provinces is best illustrated by Tables I and II.

Regardless of these utterly different facies, the full development of the Ouachita sequence is now found only 12 miles east of the outcrops of the equally complete Wichita sequence in Atoka County, Oklahoma. A well encountered Arbuckle rocks 8 miles farther southeast of the outcrops. This is an irrefutable proof that great overthrusts must separate the two facies, and that the subject under consideration is not mere overthrusting, but shear planes at the base of true frontal overthrust sheets or "nappes," which have glided west and northwest throughout considerable distances, introducing exotic rocks, deposited in an entirely different and originally remote province of sedimentation.[1] The underlying

[1]A *nappe* is a more or less thick, ordinarily but not necessarily folded and faulted mass of rocks, thrust horizontally for a considerable distance over a more stable substratum. Not uncommonly, the strata in the nappe, having been deposited in a remote province of sedimentation, are of an entirely different facies from the rocks of equivalent age in the substratum, or they may have been subjected to an extreme degree of metamorphism, so that, in some places, crystalline older or otherwise entirely different rocks overlie those building up the sequence underneath the basal thrust plane. In such situations the rocks in the nappe are called *exotic*.

Not uncommonly a pack of several superimposed nappes, each of which has been thrust over the underlying nappe, composes the overthrust mass. This overriding complex may again have been subjected to folding and faulting after it had been pushed forward. Subsequent erosion may have cut through the nappe (ordinarily on a posterior anticline or dome), and exposed either a lower nappe or the basal substratum in an *inlier* or *window* (*Fenster, fenêtre*), or it may have caused the apparent front of the nappe to recede, leaving outlying detached remnants (*outliers*) far in

autochtone (basement under the overthrust planes) must be in Wichita-Arbuckle facies. Entirely unlike the Ouachita facies, the pre-Carboniferous sediments in the Wichita geosyncline are merely a local thickening of the same rocks, which have been laid down in the same facies over the entire plateau, both north and south of the geosyncline.

Similar conditions apply to the Mississippian in the Wichita geosyncline and north of it, on the plateau. The Wichita facies sequence of the Mississippian, outlined on page 998, is known only from the eastern part of the geosyncline. There it is influenced by the Ouachita system near by. Only south of the Arbuckle Mountains, the basal Mississippian, the Woodford, is represented as chert; north of the mountains the equivalent beds are composed of black bituminous fissile shales, overlain by the higher, predominantly limestone Mississippian of the plateau ("Mississippi lime"). There is indication that, originally, the Wichita geosyncline also contained an increased thickness of Mississippian, relative to the plateau.

In southwestern Kansas and northwestern Oklahoma, the Mississippian is a very thick limestone series. This has been discovered recently in wells drilled in Clark County, Kansas, and Harper and Woods

---

front of the main overthrust mass, and lying as curiously foreign elements (*Klippen*) on the foreland.

The word nappe is French: *nappe de recouvrement* (so called by Lugeon). It is quite commonly used by English and American writers (E. B. Bailey, C. K. Leith, Bailey and Robin Willis, and many others). The equivalent German term is *Decke*. The term *thrust sheet* is also used synonymously.

The German geologists have distinguished *Decken* and *Schuppen*. The latter are minor overthrusts, where the generally smaller masses have travelled over less considerable distances. They may be called *slices* in English, as distinguished from thrust sheets.

In a nappe-structure the overriding mass, above the major basal thrust plane, or *sole*, is ordinarily broken up into innumerable slices, all thrust upon one another and separated by minor thrust faults.

The substratum, underlying the overriding masses, regardless of whether the latter consist of one nappe or several, is called the *autochtone*. The overthrust complex is named the *allochtone*.

The autochtone may extend a long distance under the nappes, stretching indefinitely in front of the mountains, where it is equivalent to the *foreland*. It is generally considerably deformed by the drag of the overriding mass, into more or less sharp folds or detached faulted, thrust, and folded slices, some of which may reach the importance of nappes. Elsewhere it may be deformed in more or less sharp open folds in the foothills. A special type of foothills-folds develops when an entire sequence of strata is sheared loose and bodily pushed forward (Jura Mountains of Switzerland).

In places, far back underneath the overriding nappes, at the old edge of the foreland, solid wedges of the crystalline substratum have been split off and pushed upward, forming *autochtonous massifs*, protruding through the overthrust complex (the massifs of the Mont Blanc, the St. Gothard, and others in the Alps).

Autochtonous folds, possibly so recumbent as to merge into nappes, are still connected, with their roots in the substratum of the major overriding allochtonous complex, which latter rests, rootless, on a substratum to which it is entirely foreign.

TABLE I[1]

SEDIMENTARY SEQUENCE IN WICHITA GEOSYNCLINE

Formations			*Thickness in Feet*	*Description of Sediments*
PENNSYLVANIAN	UPPER CISCO	Red-beds	1,000	Non-marine red-beds
		Pontotoc	250-1,000	Alternating red, maroon, and gray shales with intercalated sand and conglomerate, locally very arkosic
	Break and hiatus in Middle Cisco			*Arbuckle phase of orogeny*
	LOWER CISCO	ARDMORE BASIN GLENN[2] Hoxbar	4,000	Chiefly shales, limestones, non-arkosic sandstones
	CANYON			
	STRAWN	Deese	6,000-7,000	Sandstone and chert conglomerates, separated by shales, with minor limestone shells. Top thick limestone body
		Dornick Hills	2,500-4,000	Shales, limestones, sandstones, limestone conglomerates
				Unconformity: Wichita phase
	MORROW	Springer	3,000-3,500	Black, bituminous shales, with several sandstones
		Caney	800-2,000	Black shales
				Probably hiatus in series
MISSISSIPPIAN		Sycamore	200	Limestone
		Woodford	150-600	Chert south of Arbuckle region; shale on north
				Unconformity
LOWER DEVONIAN	HUNTON	Frisco limestone	±20	Oriskanian
		Bois d'Arc ls. Haragan marl	±60 ±100	Helderbergian
SILURIAN		Henryhouse marl	±90	Lockport (Niagaran)
		Chimneyhill	±35	Clinton (Niagaran) and Alexandrian
		Sylvan	300	Richmond
ORDOVICIAN		Viola	500-700	Fernvale (Richmond) *Unconformity* Maysville and Eden (Cincinnatian)
		Simpson	1,200-2,400	Limestones, sandstones, shales, in thin alternating beds; bituminous; Trenton to Chazy
				Slight warping
CAMBRIAN		Arbuckle	5,000-8,000	Massive marine limestone, largely dolomitic in lower part. Canadian to Ozarkian
		Reagan	300-500	Honey Creek limestone in upper part,—glauconitic, arkosic, fossiliferous. Arkosic sandstone; glauconitic in part. St. Croixan
				Major unconformity

[1]Revised by B. H. Harlton and F. A. Bush.

[2]The correlation of the Glenn sequence of the Ardmore basin represents the most reliable consensus of opinion after recent research work by B. H. Harlton, R. C. Moore, and C. O. Dunbar.

Remarks
These sediments, being largely detritus from the mountains, decrease in thickness within a short distance toward the north, the lower members failing entirely
The Arbuckle phase of orogeny occurred near the end of Lansing time, and previous to most of the Douglas deposition. There is no break, however, and still less unconformity, in northern Oklahoma and Kansas
No formations older than middle Strawn are represented in northern Oklahoma and Kansas Pennsylvanian
The Wichita orogenic phase is not represented in the Arbuckle Mountains and the Ardmore basin, but is confined to the central Wichita chains The Morrow and highest Mississippian formations are detritus from the earlier pulsations of the Wichita orogenic phase, which was confined to the Ouachita system. These deposits are restricted to the region adjacent to the Ouachitas, notably to the Ardmore basin Outside of the Wichita geosyncline they thin toward the northwest
Outside the Wichita geosyncline, on the plateau in Texas, the thickness of the pre-Carboniferous is only 1,000-2,500 feet; in Oklahoma, 1,500 feet, more or less

TABLE II[1]

PRE-PERMIAN SEQUENCE IN OUACHITA GEOSYNCLINE

Formations			Thickness in Feet		Description of Sediments
PENNSYLVANIAN	ALLEGHENY	LOWER CANYON — Francis	400-600	Total max. ± 9,500	
		Seminole cgl.	15-350		Shales and sandstones, conglomerate in top, predominantly but not exclusively erosion products of the Ouachita Mountains on the south ("molasse") The thickness decreases away from the mountains northward; maximum in Coal basin, dwindles to 1,200-1,500 feet at Tahlequah and near Muskogee
		Holdenville sh.	180-260		
		Wewoka	50-700		
		Wetumka sh.	80-120		
		Calvin ss.	0-240		
		Senora	50-500		
		Stuart sh.	90-280		
		Thurman ss. and cgl.	80-280		
		Boggy sh.	2,000-3,000		
		Savanna ss.	750-2,000		
		STRAWN — McAlester	1,150-2,500		
		Hartshorne ss.	100-200		
	POTTSVILLE	SMITHWICK — Atoka	3,000 to 9,500		Interbedded sandstones and shales; varies considerably locally. Occurs both in foreland and on the thrust sheets of Ouachitas. Sandstones predominate in northeastern section
		Unconformity: upper Wichita phase			
		MORROW — Wapanucka	0-100		Cherty fossiliferous limestone
		Johns Valley shale	Maximum 2,000		Blue-black shales; with certainty only developed on foreland and in autochtonous Ouachita belt north of Ti Valley shear plane
?	?	LOWEST PENNSYLVANIAN ? — Jackfork ss.	Maximum 6,600		Mostly sandstone in massive beds, with minor intercalations of blue and black shales, which disappear southward
MISSISSIPPIAN		PARKWOOD — Stanley sh. ?	6,000 to 10,000		Mostly blue shales, indurated into slates in places; intercalations of thin-bedded, fine-grained, dark-colored sandstones, increasing southward
		Unconformity: lower Wichita phase			
		CHESTER TO OSAGE — Hiatus ?			
		KINDERHOOK — Arkansas novaculite	250-950		Black and white cherts
UPPER AND MIDDLE DEVONIAN					
		Lower Devonian and upper Silurian missing			
SILURIAN		Missouri Mountain slate	600-1,500		Shales and slates, basal conglomerate (Niagaran?)
		Unconformity			
		Blaylock ss.			Thin sandstone with shales
ORDOVICIAN		Polk Creek sh. Bigfork ch. Womble sh. Blakely ss. Mazarn sh.	1,600-3,500		Graptolite-bearing shales, slates, cherts, with some sandstone and limestone members. Identifiable fossils range from upper Ordovician to Beekmantown
LOWEST ORDOVICIAN?		Crystal Mountain ss.	500-850		Massive gray sandstone, conglomerate at base
		Unconformity			
CAMBRIAN		Collier slate	Only 500 feet exposed		Metamorphosed shales, limestones with sandstone members; base not exposed; no lower formations are exposed or known from wells

[1]Revised by B. H. Harlton and F. A. Bush

	Remarks
OUACHITA "MOLASSE"	Down to the Hartshorne sandstone these formations are represented only in the foreland trough, not in the thrust sheets of the Ouachita Mountains. The lower members are represented only in the foredeep, not farther out on the plateau. The Wetumka is correlative with the Fort Scott limestone
OUACHITA "FLYSCH"	The foreland Atoka is Pottsville in age The base of the Pennsylvanian ("Atoka") on the thrust sheets is of Morrow age, and represents the Wapanucka The pronounced influence of the Ouachitas as a source region for the Ardmore basin Glenn sediments begins above the Bostwick horizon of the Dornick Hills formation. The lower Dornick Hills is derived from the Criner Hills (*cf.* Table I)
	The Wapanucka is represented as limestone south of the Ti Valley shear, and seems included partly in the Atoka
	The Caney north of the Arbuckles (1,600 feet) probably represents the entire Jackfork-Stanley sequence on the thrust sheets (17,000 feet), and also the Springer-Caney sequence (5,000 feet) of the Ardmore basin According to Miser, the Jackfork-Stanley is all Upper Mississippian. The writer adopts the opinion of Ulrich, that the Jackfork is lowest Pennsylvanian (lowest Pottsville), and only the Stanley is highest Mississippian and equivalent to the Parkwood formation of Alabama. The Jackfork-Stanley sequence is strictly confined to the flysch geosyncline, and represented by a hiatus on the foreland
According to Ulrich (**58**), the upper novaculite may also represent the Keokuk and Kinderhook divisions of the plateau Mississippian, thus replacing the predominant limestone facies by cherts. (Miser believes youngest beds in novaculite are of same age as Chattanooga shale.) The lower novaculite would represent the middle Devonian of Tennessee. Lower Devonian is absent	According to Miser (**43**), the Talihina chert, and underlying Stringtown shale, represent this entire sequence down to the Womble. Formations below the Stringtown shale are not exposed in the Talihina area
Known only from southern part of the Ouachita Mountains, in Oklahoma and Arkansas	

counties, Oklahoma. These rocks, which reach 1,800 feet in thickness, are identified as youngest Chester, overlying the equivalent of the "Mississippi lime." It seems possible that this Mississippian is part of the original Wichita geosyncline, and that it extends under the Anadarko basin; it may once have been represented in the region of the Wichita Mountains, before Pennsylvanian uplift and erosion obliterated all trace of it. In central Texas the Mississippian, known at the surface east of Brown County, comprises the "Mississippi lime" and overlying Barnett limestone and shale. In Hamilton and Coryell counties its thickness is only 100-125 feet. It is also present in Lampasas, Coleman, Brown, and Taylor counties, but seems to disappear farther southwest toward the buried extension of the Ouachita Mountains (**14**, **15**.)

As regards the Ouachita geosyncline, the age of the Jackfork is still somewhat in dispute. E. O. Ulrich (**58**) considers the Jackfork as basal Pennsylvanian and bases his opinion in part on plant remains (**58**, pp. 47-48). Honess obtained fauna in northern McCurtain and eastern Pushmataha counties, well within the mountains, from a sandstone 6,000 feet thick, lithologically identical with Jackfork, which proved to be of Morrow age, and which he differentiated as "Upper Jackfork" (**45**, p. 21). With Honess' approval these beds are now mapped as Atoka on Miser's new geologic map of Oklahoma (**43**). Miser and Honess bring paleontological evidence to bear, including an opinion by David White on Jackfork and Upper Stanley plant remains, that both these formations are Upper Mississippian. The flora, however, is far from complete and of an indistinct transitional character between Pennsylvanian and Mississippian. Ulrich (**58**, p. 21) considers the Stanley equivalent to the Parkwood formation of Alabama, which is highest Mississippian, younger than the Pitkin horizon of northeastern Oklahoma, and constitutes a series which is developed only in the Appalachian geosyncline, but is absent on the foreland: an orogenic deposit. The writer personally prefers the interpretation of Ulrich. In his opinion, the evidence indicates that both lowest Pennsylvanian and highest Mississippian sandstones and shales, in orogenic facies, occur in the overthrust sheets ("nappes") of the Ouachita Mountains. This is the important point for our problem. The involved structure of these mountains, which is still far from unravelled in details, will always make it easily possible that these very similar sandstones and shales are locally confused. It also seems evident, however, that no Middle Mississippian, and certainly no Lower Mississippian, is contained in the Ouachita deposits of the flysch type. Ulrich believes that the Arkansas no-

vaculite-Talihina chert series may comprise Lower Mississippian (Osage and Kinderhook divisions) as Devonian (**58**). Miser states that there is no evidence for this correlation.

In the Marathon region also the pre-Carboniferous rocks occur in a facies which is much more closely related to that of the Ouachita geosyncline than to the limestone facies of the Wichita trough and of the plateau. At Marathon is a known sequence of some 1,500-2,000 feet of siliceous graptolite shales, sandstones, and thin limestones, overlain by 600 feet of Upper Ordovician and Devonian cherts. It is necessary to go all the way to El Paso before again finding Ordovician and Silurian in a massive limestone facies; El Paso and Montoya limestones, 1,250 feet (Ordovician), overlain by 1,000 feet of Fusselman dolomite (Silurian). This is well out on the Ouachita foreland. Also, at Marathon, is found a great thickness of Lower Pennsylvanian-Upper Mississippian sediments, in flysch facies, rather similar in lithology, and very probably in age, to the same kind of sediments in the Ouachita Mountains.

STRUCTURE OF WICHITA MOUNTAIN SYSTEM

The Wichita system as a whole forms an important mountain structure, but the folding is comparatively moderate and no overthrusting on an important scale is anywhere in evidence in the visible ranges. As was lately emphasized by Melton, faulting seems to have been the chief mode of deformation in the Wichita Mountains, though folding is an increasingly important factor toward the southeast; it seems gradually to disappear westward. The abrupt slopes on the north side of the main Arbuckle and Wichita mountain arches constitute fault-line scarps. They are to a very considerable extent block mountains, notably the western units.

In this general complex, also, there are *two distinct elements*, which differ in character as well as in the time of the diastrophism: the Wichita chains proper (including the Red River ranges), and the Arbuckle Mountains. They both originate within the same intra-continental Wichita geosyncline, and contain the same stratigraphic elements in the same facies, but the Wichita and Red River ranges seemingly form true chains, and the Arbuckle Mountains are a piece of the uplifted, elsewhere little affected foreland, in front of the Wichitas, where it is traversed by an ancient resistant Hunton arch. This foreland zone was folded only by a later phase of the general Wichita orogeny. The Arbuckles are separated from the main chains by a deep foreland trough,

the Ardmore basin, which evidently was originally very much wider than it is now.[1]

The Wichita Mountains (by this is meant the hills designated under this name on the geographical map) constitute the only part of the main chains that is well exposed. They form a large complex anticlinorium. The present surface exposures are chiefly igneous rocks, with a poorly exposed mantle of Ordovician limestones, in the same development and facies as in the Arbuckles. Becker (**6**, 1930) and M. G. Hoffman (**26**, 1930) have published the most recent studies of these mountains.

The chain is expressed in three *en échelon* west-northwest and east-southeast striking ridges of granite, with injections of gabbro and porphyry. A deep syncline, now compressed into a very narrow trough, 8,000 feet deep, separates the northeast ridge from the central ridge.

Becker is inclined to explain these mountains as a mere vertical uplift, caused by the slow ascension of three batholiths early in the Pennsylvanian, instead of by folding. Some indications of contact metamorphism against the Cambrian Reagan sandstone are mentioned in support of this theory, but do not seem very conclusive. Metamorphism was observed only on the contact with the porphyry in the northeastern ridge, which may be a later intrusion (**6**, p. 43).

Hoffman, in the publication previously mentioned, contends that the igneous rocks of the Wichita Mountains are not batholiths, but that they have been injected as very thick sills into Proterozoic quartzites. The intrusion occurred in pre-Cambrian time. Upper Cambrian rests unconformably on an eroded surface of these igneous rocks, pebbles of which occur in the base of the Reagan sandstone.

Consequently, it seems that the Wichita Mountains are not the result of batholithic uplift. Though these mountains may be chiefly fault blocks, the general origin of the Wichita system, including the Arbuckle Mountains, the Red River ranges, and most probably the Amarillo Mountains, in its perfectly maintained strike and *en échelon* alignment, rising out of a marked geosyncline, is clearly the effect of compressive crustal forces on a larger scale. It is probable that the igneous masses, whatever their age and origin may have been, were pressed together later, and the intervening deep and very narrow synclines can be understood only as the result of considerable compression.

[1] A peculiarity of this foreland zone is that it still lies within the ancient Ordovician syncline. This may be explained by the fact that this pre-Devonian trough is so very much older than the diastrophism of the Wichita Mountains. This is an exceptional characteristic of the Wichita system.

The pressure origin of the Wichita Mountains is particularly well demonstrated by the existence of a marked foreland depression: the Anadarko basin, lately described again by A. J. Freie (**22**). An asymmetric foredeep of this nature, following the general strike exactly, is good evidence for the compressive character of the entire system. This foredeep is characterized by the enormous thickening of the Permian material filling the trough. It is not known whether any of the Mississippian deposits, which were reached in wells farther north, are represented here. The thickness of these sediments is more than 4,500 feet near Canute, only 25 miles from the nearest surface outcrop of granite. The thickness of the Pennsylvanian in the center of the basin is unknown, but may also be great, notably in the eastern part. Becker, assuming no particularly great thickness of this Pennsylvanian (only 1,500-2,000 feet), nevertheless calculates that the highest part of the Wichita anticlinorium was elevated structurally approximately 19,000 feet above the axis of the Anadarko foredeep.

WESTERN EXTENSION OF WICHITA GEOSYNCLINE

It is not known precisely how far west the limestone deposition of old Paleozoic sediments continued in the original geosyncline. Wells drilled farther west in this region are not known to have yielded any data about the older Paleozoic formations. On the flanks of the domes of the Amarillo ridge, only granite has been reached in the wells, immediately underlying Upper Cisco Pennsylvanian. This may be an effect of early Pennsylvanian erosion.

No very marked foredeep is in evidence here. It seems probable that the Wichita geosyncline ends not far west of the Wichita Mountains, and that the Amarillo Mountains are, still more than the Wichitas, caused by block faulting of the old basement. Clearly, however, all this must ultimately have been influenced by the same pressure which uplifted the Wichitas. The rigidly maintained strike, slightly convex toward the north, is very conclusive evidence.

Where, still farther west, the old floor is uplifted also, in the Sangre de Cristo range of Colorado and New Mexico, we find approximately 350 feet of older Paleozoic beds: thin limestone ledges and sandy limestones (Beulah to Manitou, underlain by approximately 20 feet of Cambrian Sawatch) between the Mississippian and the pre-Cambrian at the extreme northern end of the mountains, and along Arkansas River a few miles west of Salida. A siliceous limestone of Silurian age is also reported on the western side of the range near San Luis, in Costello County, Colorado (**29**).

In the southern extension of the Sangre de Cristo range in New Mexico the Upper Pennsylvanian Magdalena limestone rests immediately on the pre-Cambrian. This is also the situation in the Manzano and Oscura mountains.

It seems, therefore, that this entire western region, now constituting the frontal province of the Rocky Mountain system, was outside the Wichita province of large deposition during the early Paleozoic, which characterizes the geosyncline. The uplifts, though more or less contemporaneous with the *orogeny* in the Wichita system, were no part of it. *The Wichita geosyncline dies out in western Texas.*

TIME AND CHARACTER OF WICHITA AND ARBUCKLE OROGENIES

The principal folding of the Wichita Mountains occurred in the early Pennsylvanian. This is a very widespread orogenic phase, which affects not only this mountain system, but is greatly in evidence in the entire plateau region: all Kansas, Oklahoma, and Texas, as far south as the Llano-Burnet region and Marathon. Most, if not all, the structural features on the plateau show considerable uplift, emergence, and erosion between the deposition of the Mississippian and the advance of the younger Pennsylvanian (Cherokee) sea (**39**). According to H. A. Ley,[1] the Nemaha Mountains were elevated 1,000 feet or more above the surrounding country, and similar though less pronounced uplift occurred in the many structures in central Oklahoma, and also on the Hunton arch, as well as in Colorado and New Mexico. Evidently the entire southwestern part of the continental block of North America came under considerable stress at this period, causing the old positive elements and also minor fault blocks to become vertically displaced, rejuvenating the older fault planes and, possibly, originating new ones (**1, 16**). In the Wichita Mountains and the related chains in the Wichita geosyncline (excepting the Arbuckles) this diastrophism reached a maximum of much greater importance than on the plateau area on the north and south.

WICHITA PHASE OF OROGENY

In southeastern Oklahoma the maximum movement can be accurately dated as occurring in two phases, extending through latest Mississippian and early Pennsylvanian time. These movements, however, seem to be mere pulsations in one great orogeny, which we may name the Wichita phase. The movement, though not affecting the entire region simultaneously, was practically continuous. The Wichita system

[1] H. A. Ley, "Mississippi Lime West of the Granite Ridge in Kansas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10, No. 1 (January, 1926), pp. 96-97.

seems to have been seriously affected only by the later pulsation, beginning with the end of the Morrow period. There is no indication here of a strong orogeny in the latest Mississippian, such as we describe later for the Ouachita Mountains.

The Arbuckle Mountains are a massif of truncated folds. Folding is fairly intense in the southern part, but the northern half of the exposed mountains seems less sharply folded and more broken and faulted. In order to understand the Arbuckle orogeny properly, we have also to consider the next fold on the south, exposed in the small outcrop of the Criner Hills, a complexly folded and faulted horst, consisting largely of Ordovician limestones like those in the Arbuckle Mountains. A narrow, very deep depression, the Ardmore basin, separates the Criner Hills from the Arbuckles. It is now only 14 miles wide, but the geosynclinal folds were depressed to a depth of not less than 10 miles (**54**, cross section on Plate XVII). Overlying the thick geosynclinal older Paleozoic, it is filled with 17,000 feet of Carboniferous detritus clearly derived mostly from a southern and southeastern source. Most of this belongs to the so-called Glenn formation (Dornick Hills plus Deese) and is typical orogenic sediment derived from highlands being actively eroded. In this respect it is to be compared with the Molasse of Europe.

The Criner Hills must be considered as a direct continuation of the anticlinorium of the Wichita Mountains. The Arbuckles, however, are an entirely different feature, and they were not folded simultaneously with the Criner Hills and the other parts of the Wichitas, but considerably later. The Ardmore basin is the southeastern equivalent of the Anadarko basin, part of the foredeep bordering the front of the entire Wichita system proper. Here, however, it has been intensely compressed into a very narrow and deep trough, by the same later orogenic phase which raised the Arbuckles.

The Ardmore basin has the further peculiarity that the 3,000-3,500 feet of Springer formation, which antedates the second phase of the Wichita orogeny, is also decidedly an orogenic deposit. The basal members of the Springer may extend into the Mississippian. The lowest known fossils were found near the middle of the series. These suggest earliest Morrow. At least 2,000 feet of strata, from which no fossils have yet been described, intervene between that horizon and the fossiliferous basal Caney, which is certainly Mississippian. The top of the Springer marks the beginning of the second Wichita phase of folding. The Springer-Caney complex, therefore, may be compared with the Jackfork-Stanley sequence of the Ouachita system. The

Springer in particular may be an equivalent of much of the Ouachita Jackfork sandstone, and the Caney of the Stanley shale,[1] comprising the highest part of the Mississippian, which seems to be confined to the Ouachita geosyncline, including that of the Appalachians in Alabama (Parkwood formation). This highest Mississippian is younger than the Pitkin limestone of the Ozarks and the general plateau, and is replaced by a break in the stratigraphy and erosion on the entire foreland outside of the Ouachita geosyncline, of which the Ardmore basin forms a western embayment into the Wichita geosyncline. The writer reverts to this later when discussing the orogeny of the Ouachita system. This orogenic Lower Carboniferous indicates that the movements of the Wichita phase originated in the region southeast of the Arbuckles before the climax of folding was reached in the Wichita chains. Most of the Springer-Caney series, however, seem to have been derived from the Ouachitas.

The Middle Carboniferous Wichita diastrophism, therefore, was of considerable duration, from latest Mississippian to early Pennsylvanian. *It showed two marked pulsations: one in the latest Mississippian,* probably immediately after Pitkin time, and very possibly confined exclusively to the Ouachita system, causing the deposition of the Ouachita flysch and the equivalent Ardmore Caney-Springer sequence; *the second phase, at the end of the Morrow,* causing the folding of the Wichita system proper, and the deposition of the Pottsville molasse of the Ouachitas and the Glenn detritus of the Wichitas (Ardmore basin, et cetera). To which of these two phases the movements of the structures on the plateau, between the Middle Mississippian and the Cherokee submergences, must be referred can not be ascertained: they are merely general Wichita-phase movements.

ARBUCKLE PHASE OF OROGENY

The Criner Hills were folded simultaneously with the Wichita Mountains after the close of Springer (Morrow) time. *This folding did not affect the Ardmore basin.* Here, and in the entire area west of the Wichita River, including the *southern* Arbuckles, there is no evidence, either stratigraphic or structural, that any movement began before late in Deese time (Strawn), at the earliest. No angular unconformity interrupts the essential parallelism of the strata from the Cambrian Reagan sandstone to the top of the Hoxbar (Canyon). Then, during Cisco time (approximately at the end of the Thrifty period of central Texas), there-

[1] In the writer's opinion, the 1,600 feet of "Caney" north of the Arbuckle Mountains, in all probability, comprises both the Springer and the Caney of the Ardmore basin.

fore near the end of Pennsylvanian time, a tremendous break occurs. Northwest of Ardmore the red base of the Pontotoc conglomerate of late Cisco age overlaps the upturned and truncated edges of the entire series of formations down to the pre-Cambrian, transgressing approximately 25,000 feet of sediments. Overlapping of the top of the Deese and the Hoxbar formation on the southern flank of the Criner Hills, and limestone conglomerates, suggest that the first precursory movements may have commenced earlier in the southern range.

We have named this diastrophism the Arbuckle phase. This effect of a renewed north-northeast push again affected the Criner Hills, compressed the originally much wider Ardmore basin into the present very deep and narrow trough, and strongly folded and crumpled the southern end of the resistant Hunton arch, thereby creating the Arbuckle Mountains.

The Wichita Mountains were also reëlevated at this time, and, probably, the three original ranges pressed much closer together. The Anadarko deep was depressed farther, became more asymmetric, and began to be filled with the great thickness of late Cisco and Lower Permian sediments, largely originating from the Wichitas.

The Amarillo Mountains were also rejuvenated and now yielded the erosional detritus of the "granite wash," so important in the petroleum geology of the region.

As we have seen, there was no folding in the Arbuckles at the time of the Wichita phase; nevertheless, there occurred a general upbulging of the southern end of the Hunton arch. Powers (**49**, pp. 1052-53) describes a conglomerate at the base of the equivalent of the upper part of the Dornick Hills series of the Ardmore basin in the Mill Creek syncline, north of the Arbuckle chains proper, containing an assortment of pebbles proving that the sediments of the Arbuckle sequence, with the exclusion of the granite, had been uplifted and eroded at that time in the region. This conglomerate and the overlying Deese rocks are structurally disconformable with the underlying Ordovician rocks. This disturbance is perceptible as far north as Seminole County, where a pronounced unconformity separates the Wapanucka (overlying the "Cromwell oil sand") from the succeeding Boggy formation. Regional emergence and active erosion were in progress at this time in the northern Arbuckle region, resulting in deposition of a *non-arkosic* limestone conglomerate, the Franks conglomerate, which farther north grades into the Hartshorne, McAlester, Savanna, and finally the Boggy formations. Evidently at this time erosion had not yet cut down to the

pre-Cambrian and the northern Arbuckles were merely bulged, not folded. Certain movements continued after the Atoka, as the Hartshorne overlaps the Atoka series, and, in turn, the Savanna overlaps the McAlester. Disturbance was renewed in Thurman time (48).

LATER DEVELOPMENT

In Wichita-Albany time erosion had evidently ceased in the Wichita Mountains, for the Stillwater beds, of this age, consist of blue shales and limestones, layers of anhydrite and dolomite. The later Permian Red-beds give evidence of renewed erosion, but these materials came *not from the Wichitas, in the south, but from the Ouachitas, in the east.* The Wichitas must have been more or less completely peneplaned and buried by that time.

The Arbuckles, therefore, must be chiefly considered as a piece of the foreland, made specially resistant by the presence of the ancient Hunton arch, which was first bulged by the Wichita phase, and afterward folded and faulted by the Arbuckle phase. This later phase lifted the arch very much higher and drove the Pennsylvanian sea far toward the north. The highest Cisco is deposited in Red-bed facies, with plants and remains of land vertebrates. The sea readvanced in Shawnee (Vamoosa) time, at the very end of the Pennsylvanian epoch.

These developments demonstrate the length of Cisco time as a whole. Only in the middle part of this epoch a very important orogeny occurred, and before the end of the Pennsylvanian, there was time almost completely to peneplane the new mountains.

BURIED ELEMENTS OF WICHITA SYSTEM

The features so far described are the only exposed parts of the Wichita system. Extensive drilling in this region has given a fair idea of how these structures are connected in the subsurface.

Buried *en échelon* folds, belonging to the general anticlinorium represented by the Criner Hills (the Hewitt, Healdton, Loco, Woolsey, and Nellie anticlines) connect these anticlines, across the intervening depression (80 miles), with the exposed eastern end of the Wichita Mountains. That the Criner Hills, which formerly were also buried beneath the Deese deposits, are now exposed at the surface, just south of the Arbuckle Mountains, though all the rest of the great anticlinorium is buried, is probably the result of the positive influence of the Hunton arch. The prominence of the buried uplifts in the Nocona and Bulcher folds, still farther south, may be the result of the same influence.

The trough of the Ardmore basin can be traced farther northwest and southeast under the blanket of Red-beds and Cretaceous. It seems to widen where it was less subject to compression against the buttress of the Hunton arch. The folds at Velma, Graham, Caddo and Overbrook, and Madill are evidently situated within this basin. They are typical Arbuckle-phase structures, consisting of steeply compressed Pennsylvanian, unconformably overlain by latest Pennsylvanian and Permian Pontotoc and Red-beds. Possibly, the Preston anticline in the Cretaceous may indicate a buried extension of these same conditions underneath the Ouachita nappes, the presence of which has been demonstrated by wells in Grayson and Fannin counties, Texas (**49**, p. 1058).

All the foredeep folds here discussed are true foothills folds in front of the principal Wichita chains, comparable with the open folds in front of the Ouachitas in the Coal basin of Oklahoma and the Arkansas Valley (Tomlinson, **54**, notably Fig. 2).

The Wichita-Criner Hills range, although seemingly the most important, is only the frontal chain of the Wichita system. Farther south and apparently separated from the frontal chain by another deep basin, filled with Pennsylvanian and Permian detritus, the drill has again revealed several anticlinal structures, overlying buried pre-Pennsylvanian ridges. They occur along Red River, particularly in northern Texas, in *échelon* alignment, following the same Wichita strike.

The deep intervening Waurika-Ringling-Marietta basin is indicated by many wells, which have penetrated nearly 5,000 feet of Permian and Upper Pennsylvanian, down to the Deese, without reaching any older strata. In parts of this basin, notably in its southeastern part, more of the enormous sequence of the Ardmore basin Glenn series may be represented. Even as in the Ardmore basin, minor folds, all following the same trend, occur in this depression.

Also south of this synclinorium, at Oscar, the Deese rests on Ordovician limestone and pre-Cambrian. Whether pre-Deese Pennsylvanian is present or not in the basin, can not be affirmed.[1]

The same condition as at Oscar exists south of Red River in the Nocona fold of Montague County, and still farther southeast in the Bulcher anticline in Cooke County (J. R. Bunn, **12**, 1930; cross section).

The Red River arch seems to be composed of two major chains, each formed by several minor structures aligned *en échelon*. The northern

[1]In Sec. 31, T. 4 S., R. 9 W., and in Sec. 28, T. 5 S., R. 8 W., Cambrian sediments were encountered below the Deese. These are thought to be equivalent to the Honey Creek lime of the Arbuckle formation of Oklahoma and the Wilberns formation of Texas (communication from F. H. Lahee).

chain begins in northeastern Denton County, Texas, where wells encountered Ellenburger limestone at 1,400 feet. Wells in Cooke County have been drilled more than 1,500 feet into such limestones, indicating that geosynclinal development persists. A zone of uplifts of granite, with "granite wash" and old Paleozoic limestones on their flanks, extends in the subsurface from Denton and Cooke counties into southern Jefferson County, Oklahoma. The second southern chain extends from northern Clay County, westward through Wichita and Wilbarger, into Foard County (**15**, Plate VII). Several wells encountered diorite, granite, and granite wash (probably Upper Cisco) on the ridges, whereas, along the flanks, the wells remained in Ordovician limestones. The Bend lies unconformably on the Ordovician on the southern flank of the arch, indicating the pre-Pennsylvanian phase of the Wichita orogeny.

The Pennsylvanian seems to be confined to Cisco and Upper Canyon. The Strawn of central Texas extends from the Llano-Burnet region, northward to Wichita and Clay counties, where according to Powers (**49**, p. 1061) it is overlapped unconformably by Upper Canyon. This points to movements antedating the Arbuckle phase. The latter is clearly indicated by strong folding in the later Cisco, and Permian overlying the folded and eroded Pennsylvanian (**31**, 1929).

STRUCTURE OF OUACHITA MOUNTAIN SYSTEM

The present exposed Ouachita Mountains occupy a belt 50-60 miles broad, extending from Atoka County, Oklahoma, eastward into Pulaski, Saline, and Hot Spring counties, Arkansas, or a length of 215 miles. This is only a minor part of the entire chain. All along the southern and eastern edge of the present exposure the mountains disappear below the Cretaceous and the Tertiary.

Only on the western and northern sides of the Ouachita Mountains is the edge of the structure exposed in the form of large overthrust faults. Wells have encountered the Ouachita rocks in a belt approximately 40 miles wide south and southeast of the outcrops along a line extending from Boswell in Choctaw County, to Bokhoma in McCurtain County, Oklahoma, and beyond the Arkansas line, to the vicinity of Fordyce in Dallas County, and west of Rison in Cleveland County, Arkansas. The Ouachita facies has also been found on the Preston anticline.

Recently a good synopsis of the structure of these mountains has been published by Miser (**44**, 1929), from which publication the writer is liberally quoting. Another important study by Melton (**41**) appeared in 1930. Reference may also be made to the recent *Arkansas Geological*

Survey Bulletin 3 (**18**). Miser gives an interesting structural map in Plate II. The recent geologic maps of the states of Oklahoma and Arkansas are referred to for the general geology (**43** and **9**).

The structure, however, is very complicated and the region has not been worked in sufficient detail to permit us to consider these maps as final and complete. The great thrust faults, which are conspicuous in the Oklahoma section, fail almost completely on the map of the Arkansas section. This must be erroneous, as is discussed later.

OVERTHRUST OR NAPPE STRUCTURE OF OUACHITA MOUNTAINS

The Ouachita mountain structure is composed of several folded nappes, which have been thrust on and over each other. In general it closely resembles the structure of the southern section of the Appalachian Mountains. In front of the overthrusts lies a zone of open folds in the foreland, which gradually decrease in intensity toward the north. This also is analogous with the Appalachians.

As discussed earlier in this paper, the rocks in the Ouachita Mountains are of an entirely exotic character, as compared with the sediments deposited in the Wichita geosyncline and in the whole plateau region. Apart from this suggestion, the structure itself also clearly indicates thrust sheets or *nappes*, pushed far north and northwest from some southern source, now buried beneath the Cretaceous. The complex is tremendously contorted and broken, not only by several distinct large shear planes, but by innumerable larger and smaller thrust faults and joints, and the rocks are distinctly metamorphosed and show cleavage in several places. The Stanley shales are metamorphosed in the entire region and are in many places turned into brittle stony slates. Most of the sandstones have a chloritic and sericitic cement, and in many places the formations are cut in all directions by innumerable quartz veins.

The crushed structure of the thrust blocks is explained by the fact that the moving mass was a pack of rather incompetent shales and shaly sediments, containing many sandstones, including some very massive members. The whole series, to the top of the Cambrian, in so far as it is known, is nearly 30,000 feet in thickness.

The Choctaw thrust fault forms the northwestern edge of the Ouachita structure, but another shear that extends through the Ti Valley shale area, with poor, largely still unworked exposures, seems to mark the northwestern boundary of the thrust sheet which contains the Ouachita facies of rocks. This was already remarked by Ulrich (**58**, pp. 26-27) and by Powers. Better marked is the Winding Stair fault

somewhat farther south. On the northern side of the Ti Valley shear, the exposed rocks are more nearly like those of the general foreland region, including the Arbuckle Mountains, whereas on the south side they are altogether different in lithology. Only two formations seem to be common to the two areas in a more or less similar facies: the Woodford chert (basal Mississippian) and the Atoka formation (Lower Pennsylvanian) (**45**, pp. 21-22). In the Ouachita facies sequence the Woodford is probably represented in the middle part of the Arkansas novaculite (**58**, pp. 24-25). Between the Ti Valley fault and the Choctaw fault the sequence lacks both the Jackfork and the Stanley formations (highest Mississippian and possibly some lowest Morrow), which are 15,000 feet in thickness on the Ouachita nappe immediately south of the Ti Valley and Winding Stair thrust planes. North of the Ti Valley shear the Caney shale rests immediately on Woodford chert, with a seemingly broken contact (**58**, p. 27). The "Caney" member is not represented on the more southerly thrust masses. Here the Atoka directly overlies the Jackfork. There is disagreement as to whether the "Caney" in eastern Atoka County, east of the Black Knob chert ridge, within the thrust sheets, is real Caney. Ulrich proposes a different name: "Johns Valley shale" (**58**).[1]

Dake (**19**) was the first who, to the writer's knowledge, suggested in 1921 that the exotic rocks of the Ouachita Mountain region were thrust northward a long distance over strata that have the same facies as those of the Arbuckle Mountains, near by on the west. That wide overthrusting must be accepted to explain the abrupt change of facies has later been recognized by other geologists: Dott (**21**, 1927), Ulrich (**58**, 1927), Powers (**49**, 1928), Cheney (**14**, **15**, 1929), and Miser (**44**, 1929). For several years the writer has often expressed the view in correspondence, and to colleagues on excursions in the region, that the Ouachita Mountains had an alpine thrust-sheet structure, (*cf.* also **49**, p. 1042). Ulrich expressed the belief in 1927 (**58**) that the Ouachita rocks originated in a geosyncline altogether different from that of the Arbuckle facies, separated by another foreland, and that,

[1]There is considerable confusion regarding the formations described under the name "Caney." We have mentioned already on page 1011 that the Caney north and east of the Arbuckle Mountains seems to comprise both the Caney and the Springer of the Ardmore basin. The Caney of the foreland and of the Ouachita nappes is another illustration of confusion. The writer will revert to this problem in another paper containing a discussion of the exotic boulders of the Ouachita "Caney" (W. A. J. M. van Waterschoot van der Gracht, "Pre-Carboniferous Exotic Boulders in So-Called Caney Shale in the Northwestern Front of the Ouachita Mountains of Oklahoma," *Jour. Geol.*, Vol. 39, No. 8 (November-December, 1931)).

"probably during early Mesozoic time," the deposits of the Ouachita basin were "thrust into the middle and eastern parts of the geosyncline, in the western part of which the Arbuckle sequence of almost entirely different deposits was laid down." Except for the Mesozoic age of the final overthrusting, Ulrich's and Dake's interpretations probably approach the truth more closely than any other views which have been expressed in print.[1]

That the Winding Stair shear plane, and certainly the Ti Valley shear plane, are true low-angle thrust planes is proved by the Potato Hills window, north of Kiamichi River (cut by the county line between Latimer and Pushmataha counties). This was discovered and described by Miser (**44**, pp. 18-19 and Fig. 6). The Carboniferous, as well as older rocks (Talihina series), appear here in an opening in a body of overthrust rocks of Ordovician, Silurian, Devonian, and Mississippian age. The thrust-plane nature of the indistinct Ti Valley fault zone is clearly indicated by three similar, smaller, window-like areas in the shale lowlands of the Ti Valley, near Wesley and along the branches of Brushy Creek, on either side of the town of Ti (**43**). These exposures show Caney shale overlying Woodford chert (Talihina) with a broken contact, suggesting a tectonic juxtaposition. Under the chert lies some very siliceous limestone, the fossils of which indicate Lower Devonian (**58**, p. 27).

The Boktukola and Octavia faults are also decidedly low-angle thrust planes. Mapping in 1923 by Honess in McCurtain County, southeast of the Boktukola fault in the area of pre-Carboniferous rocks, seems to have revealed this. He not only shows faults around much of the central part of the pre-Carboniferous area, but also that the Cambrian and Lower Ordovician strata there are not folded like the strata surrounding them (Miser, **44**, pp. 21-22, and Fig. 7). This indicates either another window or an outlier of another sheet. The fault surrounding the McCurtain window may be a southward continuation of the winding, subsequently warped Boktukola fault.

In order to understand the difficulty of mapping the thrust faults in the eastern Arkansas section of the mountains, one must bear in mind that the Atoka formation changes locally from sandstones into shales and *vice versa*. Only in the northeasternmost exposures does it, seemingly, consist very largely of sandstone. At many places in the southern exposures, the formation consists predominantly of shales. At the contact with massive sandstones, thrust planes are clearly in evidence.

[1]Not all the geologists cited seem equally convinced of the great distances these overthrust masses may have travelled. Miser suggests 20 miles, Dake "scores of miles," Ulrich "a hundred or more miles." The latter also compares them with the Alps and the Himalayas.

Most of them are mapped on the contact of the Jackfork sandstone with shales.

In Arkansas there is still the massive Jackfork sandstone approximately some 6,000 feet in thickness, but here the outcropping rocks happen to consist far more of Stanley shales than in Oklahoma. The Jackfork member is seen to be bent into closely compressed and broken folds in the southern part of the mountains, some of which are overturned. Thrust planes are little in evidence in exposures of this character, and can be located only after very detailed survey and paleontological work in the poorly exposed shales.

On the geologic map all the major thrust planes of the Oklahoma section seem to pass eastward into shale areas and become lost. The question is whether they are not really present. On this connection it is interesting to draw attention to the Ti Valley shear in Oklahoma, almost the most important feature in these mountains, as it divides the autochtone facies of the foreland from the Ouachita facies. On the recent map of Oklahoma, however, only small disconnected parts of it have been traced.

The geologic map of Arkansas makes it seem possible that the overthrust mass, which overlies the Choctaw fault, has been preserved much farther north in Sebastian and Logan counties, Arkansas, at least in outliers. Even some patches of "Jackfork" have been mapped there, a formation conspicuously absent anywhere else in the foreland. These patches are marked between Washburn and Chismville, and just south of Waveland. The relation seems insufficiently proved. If this is correct, it suggests northern "klippen"—outliers of southern nappes.[1]

If there is so much overthrusting in the Oklahoma section, a similar structure should certainly be expected, and to an increased degree, just south of the great Ozark buttress, which should have caused increased compression. That the compressive forces have not decreased is shown by the continuation of strong open foothills folding in the Carboniferous foreland, certainly to no less degree than in Oklahoma (**9**, **18**).

The general arcuate structure, which after a slight concavity towards the north in Polk and Montgomery counties, Arkansas, turns convex in a pronounced manner also in Garland and Saline counties, is an additional indication of a powerful northward push. The foreland folds indicate a still more eastern convex loop also in Faulkner, Cleburn, and White counties, north of the area where the mountains themselves are already buried under the Tertiary.

[1]See footnote, pp. 1000-01.

The Arkansas sections drawn by Purdue and Miser and published by the latter (**44**), recall very strongly similar sections constructed for the Alps, before the thrust (nappe) structure of these mountains was generally recognized. There these sections have been changed materially. They are now interpreted as superimposed slices, which have been refolded together. Special reference can be made to the frontal part of the High Calcareous Alps in Glarnerland or the Median Pre-Alps of the Haute Savoye and Freiburg (L. W. Collet, **17**). In the Variscan mountain massifs of Central Europe the nappe structure has only very recently been recognized in its complete and enormous extent.

The writer also calls attention to the fact that it is not exceptional for a large thrust sheet (nappe) to break into very many slices, which may be either slightly thrust over each other, by ordinary thrust faults, or develop into much more widely sliding subordinate slices. The whole is then underlain by the major shear plane. In the front zone of the northern Rocky Mountains, in Alberta, there is an example of the first kind (as ascertained by latest drilling). Many other examples exist elsewhere in the world. Illustrations of the second kind of structure are developed in the Alps on a magnificent scale.

The writer feels convinced that further detail work in the Arkansas section of the mountains will reveal a structure of nappes of no less, but rather greater, importance than in Oklahoma. The mechanics of the entire region demand it, as well as the pronounced foreign character of the Ouachita sequence.

A further strong proof of the nappe structure of the Ouachita Mountains is found in the exotic boulders of Caney shale, seemingly "tectonic moraine" occurring as far east as the town of Stapp, on the Arkansas state line. This problem will be discussed elsewhere.[1]

The striking fact that none of the Ouachita folds shows a crystalline core, and that the pre-Cambrian rocks are nowhere revealed at the surface or reached by wells, also strongly suggests a nappe structure. These mountains have this feature in common with the frontal zone of all major thrust chains, including the Appalachians, the Variscan Mountains of Europe, the Alps, the Carpathians, and many others. This strongly contrasts with such intra-continental ranges as are less or not at all overthrust, as the Arbuckle and Wichita chains, which show a pronounced uplift and baring of pre-Cambrian basement rocks.

Normal foreland structure is found in the Boston Mountains and in the adjoining part of the Arkansas Valley. Here the strata lie horizontal, are cut only by normal faults, and the Magnesian limestone series of

[1] W. A. J. M. van Waterschoot van der Gracht, *op. cit.*

the Ordovician, here approximately 1,000 feet thick, in the normal Plateau limestone facies and development, rests on pre-Cambrian rocks, as proved by borings in Arkansas and an outcrop at Spavinaw Creek in Oklahoma.

The Arbuckle-Wichita chains pass under the Ouachita thrust sheets. The manner in which the eastern end of the Arbuckle Mountains abuts against the Ouachita thrust masses, shows that the first must pass underneath the latter. As early as 1921 Dake (**19**) suggested this, and Honess and Miser support his theory. The Hansen well in T. 4 S., R. 11 W., in southern Atoka County, encountered Arbuckle-facies rocks in the entire section (Miser, **44**, p. 18). This proves not only that the overthrust rim of the Ouachitas must continue in an almost due south course in the subsurface, as the well must be west of it, but also that the Arbuckle facies continues southeast; therefore it *must* be overridden by the Ouachita thrust sheets.

Miser, Honess, and others believe that the many remarkable asphalt deposits of the Ouachita Mountains of Oklahoma and Arkansas supply another proof that the petroliferous rocks of the Wichita facies underlie the Ouachitas.

It can be seen, therefore, that the theoretical probability that the chains of the Wichita system pass under the Ouachita Mountains and continue in the underlying autochtone, is supported by considerable fact. The fact that wells on the Preston anticline (*cf.* p. 1016) have found Ouachita-facies rocks underneath the Cretaceous, does not conflict with this view. The Wichita trend of this anticline may be caused by the underlying autochtonous substratum, but be overlain by Ouachita nappes, which the wells, of course, have not pierced.

TIME OF OUACHITA OROGENY

Previous writers have not been very clear as to the age of the diastrophism in the Ouachita Mountains. It was generally placed "somewhere in the Pennsylvanian;" many preferred late Pennsylvanian (Miser); lately, however, Melton (**41**, 1930) advanced arguments in favor of an important orogenic phase after early Permian time. Much argument for a pre-Atoka phase has been based on chert conglomerates in the Atoka and succeeding Lower Pennsylvanian formations in the Lehigh basin, north of the town of Atoka, on the western edge of the Ouachitas. These were supposed to have originated from the Black Knob ridge. Hence this ridge should have antedated the deposition of the Pottsville Atoka formation; it should have existed in this particular location, and not have arrived there by a much later overthrust. Melton

advanced rather convincing argument that this assumption is incorrect, and, moreover, that it does not seem to be the same chert. He believes that the conglomerate in the Lehigh Valley autochtone entirely antedates the Ouachita overthrusting and that the pebbles originated from rocks in the Wichita chains, exposed to erosion after the Wichita phase, shortly previous to Atoka time, and entirely previous to the Ouachita overthrust. Other Atoka conglomerates give evidence that ridges in Wichita-Arbuckle facies yielded detritus to Lower Pennsylvanian formations in this region. Powers (**49**, p. 1041) mentions a conglomerate of chert and Ordovician limestone pebbles in basal Atoka a mile south of Stapp in LeFlore County. This conglomerate is not to be confused with the exotic blocks in the "Caney shale," both east and west of the same town of Stapp, which will be discussed elsewhere.

WICHITA OROGENIC PHASE IN OUACHITA MOUNTAINS

Though the foregoing remarks support the view that certain chert conglomerates in strata of Pottsville age had no connection with the Ouachita overthrusting, they indicate that there did occur movements and uplift of early Pennsylvanian time in this region, either in the Ouachita Mountains or in their Wichita-facies autochtone. The enormous development of the asymmetric Pottsville foredeep and the supply of clastic material to keep this great trough filled practically at sea level (as proved by the occurrence of coal seams), is ample proof that somewhere back in the Ouachita Mountains a very important orogeny and subsequent erosion occurred, yielding this body of derived sediments (molasse). *This heavy Ouachita sedimentation (Ouachita molasse) marks the second, early Pennsylvanian pulsation of the Wichita orogenic phase* (*cf.* p. 1012). It does not seem probable that this Lower Pennsylvanian detritus originated exclusively from Wichita-Arbuckle rocks underneath the present Ouachitas. The Woodford and the cherty Ordovician limestones no doubt contributed considerable chert residue, but where these formations yielded material, they prove their presence by limestone pebbles. Only Ouachita rocks could have yielded easily the conspicuous prevalence of chert mixed with very little if any limestone fragments, so noticeable in these foredeep sediments. It is shown later in this paper that exactly the same applies to the Strawn-Millsap formations of eastern Texas, originating from an eastern source, in a foredeep which is the equivalent of the Oklahoma-Arkansas coal basin (**50**). This indicates that Ouachita rocks were subject to erosion in Pottsville time, much farther south of their present outcrops, and south of the assumed southeastern extension of the Wichita chains in their autochtone.

The Glenn formation of the Ardmore basin was not only derived from Wichita chains on the south, but also, to a very considerable extent, from the southeast. Consequently, highlands must have existed in this direction at that time, probably representing an early Pennsylvanian phase of the Ouachitas, rather than an extension of the Wichita chains. There occurred, in fact, a remarkable interchange of sedimentation in the Ardmore basin. Some material (Bostwick conglomerate in the Dornick Hills and most of the Hoxbar) was clearly derived from the Wichita chains; other sediments (the entire Deese and most of the post-Bostwick part of the Dornick Hills formation) seem as clearly to have originated largely from Ouachita-facies rocks, and had their main source farther southeast. For details see Tomlinson (**54**).

There exists, therefore, considerable evidence that, throughout Lower Pennsylvanian time, from Bend to Canyon, uplifted areas subject to erosion prevailed, not only in the Wichita province, but also in the Ouachita facies.

Farther south an earlier important uplifting must necessarily have occurred, antedating the movement which, at the close of Morrow time, initiated the deposition of the sediments (molasse) of the Atoka and higher Pennsylvanian beds in the Coal basin foredeep. The sudden development of sedimentation in the latest Mississippian, depositing more than 17,000 feet (20,000 feet in McCurtain County, according to Honess) of orogenic sediments (flysch) seems ample evidence, particularly in consideration of the absence of any very active sedimentation during the preceding earlier Paleozoic periods in the Ouachita province, and the probable absence of the bulk of the Mississippian. There were only 3,000 feet of aggregate thickness of sediments deposited during the entire Cambrian, Ordovician, Silurian, and Devonian. It is doubtful whether there was any deposition here in Lower and Middle Mississippian; if there was, it was largely gelatinous silica in extremely quiet water, resulting in cherts. *This great deposit (of flysch type) marks the earlier, late Mississippian pulsation of the Wichita orogeny.*

This late Mississippian sedimentation came from a southern source. Thick beds of sandstone appear in the shale sections in this direction. Many small pebbles in the Jackfork sandstone of the southern outcrops become less plentiful toward the north. All this indicates highlands on the south yielding an enormous amount of erosional detritus, so much, in fact, that *only a very active orogeny in the hinterland could explain it.* A mere uplifting of an old "borderland" would be entirely inadequate.

A sedimentary mass of this character and in such quantity requires *actively rising mountain chains.*

These southern mountains consisted in large measure of acid igneous and metamorphic rocks. All sandstones contain bits of fresh plagioclase, and many of the coarser layers contain fragments of black shale, slate, chert, micaceous schist, porphyritic basic rocks, granitic quartz, muscovite, biotite, tourmaline, garnets, et cetera. The rarity of orthoclase and microcline may be explained by reason of their relatively easy destruction by decomposition. The large amount of chlorite, present with sericite as a binding material in practically all the sandstones, indicates that the original cement must have been ferruginous. Considerable carbonaceous matter and bits of carbonized wood indicate that vegetation must have grown on the highlands in the hinterland (**27**, p. 196).

It already has been remarked that these highlands must have been situated much farther south before the geosyncline became strongly compressed in the later Wichita phase and finally by the last overthrusting, thereby greatly shortening the distance.

The age of this early pulsation of the Wichita orogeny must be very late in the Mississippian, in the transition period near the lowest Pennsylvanian (Morrow). In Ulrich's opinion (**58**, pp. 23-24), the Stanley is equivalent to the Parkwood formation of Alabama and Tennessee. It is similar in position as well as in lithologic character. Ulrich thinks that the Jackfork may already represent lowest Morrow, a part not deposited outside of the foredeep. The Parkwood is younger than the Pitkin limestone, which lies at the top of the eroded Mississippian in northeastern Oklahoma. Here, and in most other areas within the American continent, the Parkwood stage is represented by a considerable break: the widespread unconformable contact of the Pennsylvanian and Mississippian. Only in the (southernmost) Appalachian and the Ouachita geosyncline, therefore, would this gap be filled by the orogenic flysch sediments, deposited in a deep fronting an earlier range. This forms another link connecting the Ouachitas with the Appalachians (**39**).[1]

[1]In northwestern Alabama the foreland coal measures are separated from the underlying Mississippian strata by a hiatus of great magnitude, which is in part represented by the Parkwood formation of the Birmingham and Shades valleys. It may occur in the subsurface of the eastern part of the Warrior syncline, as indicated by borings. The Parkwood is an almost unfossiliferous sequence of gray and greenish sandy shales, with some thin-bedded sandstones, known to have a thickness of 3,000 feet. In several respects it is extremely similar to the Ouachita flysch deposits, in medium distance from the mountains. It is totally lacking farther west: it fails in the western part of the Birmingham Valley. It is also absent farther north.

PRE-WICHITA OROGENIC MOVEMENTS

In the frontal zone of the Ouachita province older minor movements of Mississippian time are indicated by a seeming unconformity, separating the Arkansas novaculite and the Upper Mississippian flysch sediments, indicating uplift and emergence before the forming of the Ouachita geosyncline. Chert conglomerates rest on the novaculite in the Potato Hills; they are also found at the base of the Stanley shale in the southern outcrops. North of the Ti Valley shear plane, the autochtonous Caney seems to lie on different members of the Woodford at different exposures (**49**, p. 1039). Jackfork and Stanley are not represented there. This movement indicates the beginning of the first pulsation of the Wichita phase.

The widespread unconformity on the top of the Hunton, under overlapping Lower Mississippian (Chattanooga-Woodford) in the Ozark region and on the Hunton arch, and throughout the Mid-Continent plateau, seems to reflect a still earlier phase, which, though faint in the northern zone, could be conceived as a reflection of more important movements in the hinterland, the first precursory warpings of the late Paleozoic orogenic cycle, beginning with the Wichita phase. Similar precursory folding, this time of considerable importance, occurred in the northern Appalachians (Acadian phase of Blackwelder, **18**). In the Llano-Burnet uplift, in the foreland of the East Texas front of the Ouachita system, the chert underlying the Mississippian Barnett shale, which possibly represents the Woodford, also reposes unconformably on the eroded surface of the Ellenburger limestone.

Charles Schuchert, F. B. Plummer, and Frank Gouin also claim early Mississippian movements for the Wichita chains.

SUMMARY OF EARLY CARBONIFEROUS WICHITA OROGENY IN OUACHITA MOUNTAINS

The early, largely epeirogenic, movements seem to have originated in the lowest Mississippian (Acadian phase?). *The principal orogeny*, of great magnitude, occurred in two pulsations and lasted from the latest Mississippian well into Pottsville time. *The earlier pulsation* created a great flysch deposit: 17,000-20,000 feet of Stanley-Jackfork sediments in a wide foredeep, which may have extended as far northwest as the Arbuckle region (Arbuckle Caney). It extended in an embayment into the Wichita geosyncline in the Ardmore region. These sediments originated from crystalline and metamorphic ranges.

The later pulsation began near the end of Morrow time (Wapanucka). It is indicated by considerable unconformities (as on top of the Springer).

It is contemporaneous with the Wichita folding in the Wichita geosyncline. There are no clear indications *how* the folding affected the Ouachita chains, but that it did affect them is clear. A new foredeep originated, considerably in front of the original geosyncline and this became filled with 17,000 feet of sediments (molasse), derived from a southern source, where important uplift and active orogeny *must* have occurred, creating chains composed of old Paleozoic and also flysch sediments. Intramountainous basins were also formed, filled with molasse-derived sediments.

These two pulsations, which were practically continuous, as they followed each other without perceptible break, together constitute the Wichita orogeny in the Ouachita Mountains. Later gentler movements continued in Bostwick, Savanna, or Thurman time. These may belong either to the Ouachita Mountains or their Wichita-facies autochtone.

ARBUCKLE OROGENIC PHASE

We have no direct indication in the Ouachita system of the important Arbuckle orogenic phase of Middle Cisco time. Within the Ouachitas no strata of this age exist. This does not prove, however, that the earlier sequance was not again affected. It would be possible that this had occurred, because this phase is so very much in evidence in the Marathon Mountains, which we consider as the southwestern extension of the Ouachita system. However, the fact that the Pontotoc and the general red facies in southeastern Oklahoma and northeastern Texas seem exclusively controlled by the Wichita chains, is an argument against an important Arbuckle phase in the Ouachitas. As early as Hoxbar (Lower Canyon) time the Ouachita Mountains seem to have ceased to be an important source of sediments.

FINAL OVERTHRUSTING OF OUACHITA NAPPES

The great forward movement of the thrust sheets in the Ouachitas seems to have occurred fairly late, possibly as late as the Permian. The analogy with the Appalachians in Alabama suggests this as a possibility. Melton's arguments in favor of this view seem persuasive. They are based on the assumption that the violent push, resulting in an overthrusting of such magnitude, should have left visible effects in the foreland. Melton describes a prominent system of joints radiating fan-wise from the convex front of the Oklahoma Ouachita Mountains into the foreland, as far north as southern Kansas. Strata as high as the middle of the Permian section of Oklahoma (Garber sandstone) are cut by these joints. There seems to be a gradation from the smooth high-constraint

joints nearer the mountains to the rough low-pressure fractures in central and northern Oklahoma. Melton develops the theory that the joints in the open folds, bordering the front of the Ouachita Mountains, were formed at the same time that the originally flatter beds of these structures were being severely tilted in the later process of folding; in other words, that these open folds should be considered as in part contemporaneous with the regional jointing and should also have been considerably deformed in Permian time.

The writer does not think that any known facts seriously conflict with Melton's theory that the final overthrusting of the Ouachitas may have occurred as late as this in the Permian. The seemingly sudden termination of the McAlester and Savanna anticlines of the open-fold zone near the middle of the Boggy shale deposition is indeed a difficulty. It has been considered an indication that these folds were formed exclusively in or previous to Middle Boggy time. These folds do not involve beds from the Thurman sandstone upward, but decided erosional unconformities underlie the Savanna sandstone. The writer is inclined to agree with Melton that the thick incompetent shale formation of the Boggy (2,000-2,600 feet) may well have counterbalanced considerable deformation and protected the overlying more competent sandstones from participating, but this does not explain erosional unconformities. These structures were certainly not formed exclusively in Permian time. The lower part of the sedimentary sequence in the foredeep was deformed more than the upper part, and considerable folding had been achieved before the later Pennsylvanian. This continuous folding is a thing which is very common in all similar foredeep troughs. It indicates slow sinking and compressive movements during the process of sedimentation. This phenomenon is very general and widespread in all the open-fold belts in foredeeps in front of the earth's major orogenies. We may refer here to the well known open-fold zone in front of the Variscan Mountains of Europe. This belt of similar coal-measure deposits presents exactly the same structural picture. The sediments also antedate the final overthrusting of the Variscan front in Holland and Belgium (*cf.* K. Lehmann, **37**, **38**, and notably H. Böttcher, **11**; also van der Gracht, **59**).

That a Permian orogenic phase revived the Ouachita system seems certain. Mention has already been made of the evidence for the belief that the Ouachitas must have been considerably peneplaned in the intermediate period before the Middle Permian, when these mountains again became an active topographic feature in southern Oklahoma and northeastern Texas. Only the chains elevated by the Arbuckle phase *in the*

Wichita system influenced the development of the Red-bed facies in the Upper Cisco and Lower Permian of these regions. In Texas this influence disappears toward the south, though the Ouachita chain is present in East Texas. Later in the Permian a change in this condition is indicated in the San Angelo-Duncan sandstones, which are clastics originating from *a new eastern source*. The later Permian beds have intrinsically the same character, though they become finer in texture. Even the heavy minerals remain the same. In the eastern part of the Permian basin, all these beds indicate an eastern and southeastern source, though of constantly diminishing topographic importance (Cheney, **14**, **15**).

The conclusion seems permissible, therefore, that the major orogeny, which created the overthrust Ouachita structure as we now know it, was probably completed only in Permian time, somewhat later than the Garber sandstone of Oklahoma (Clear Fork of Texas), possibly in San Angelo-Duncan time. Very certainly, important topographic changes occurred after the Red-bed facies controlled by the Arbuckle phase. Much coarser detritus probably originated from this Permian phase than we now find in the remaining exposures. No Permian deposits remain in the immediate vicinity of the Ouachita front. This is another example of the similarity between the American chains and the contemporaneous Variscan Mountains of Europe.

MARATHON MOUNTAINS

Near the southwestern corner of Texas, on the boundary line between Brewster and Pecos counties, an area of extremely folded Paleozoic rocks occurs as an inlier in the Cretaceous: the Marathon uplift. The general strike of the Paleozoic folds is northeast and southwest. These rocks form hilly hogback ridges on a playa-bolson plain, the Marathon basin, within a wall of rim rocks, which consist of unconformably overlying Cretaceous strata, except in the northwest, where the high limestone scarp of the Glass Mountains of Permian rocks borders the Marathon plain. This Permian is still a part of the Marathon doming. Its rocks follow the same general northeast strike and are unconformably overlain by the Cretaceous. The upper horizons of this Permian sequence belong to the southern edge of the saline series of the great salt basin of southwest Texas. The southwestern boundary of the Marathon basin is formed by Mount Ord and the Santiago Mountains. These constitute the front range of the Cordillera: Cretaceous, folded and thrust toward the east, with a north-northwest strike. They are capped by later outpourings of rhyolitic, trachytic, and phonolitic lavas, and contain syenite and basalt intrusions.

Forty miles farther southwest, near the road from Marfa to Terlingua, another smaller exposure of Paleozoic rocks occurs in the Solitario uplift. Here the Paleozoic is bared within a circular area, with a diameter of approximately 4½ miles, surrounded by a rim consisting of Lower Cretaceous strata, with Tertiary—Recent igneous rocks: felsite, rhyolite, and basalt. The Paleozoic formations are exposed in several fault blocks, which contain closely compressed folds striking north-northeast. Local divergences of the strike seem largely caused by overthrusting and the shuffling of fault blocks. The formations are very much disturbed and the folds closely pressed.[1]

SEDIMENTARY SEQUENCE

The older Paleozoic rocks and the Permian Glass Mountains have recently been described by J. A. Udden, C. L. Baker, and E. Böse (**57**, 1916), Udden (**55**, 1917); Baker and W. F. Bowman (**2**, 1917); P. B. and R. E. King (**33**, **34**, **35**, **36**; 1926, 1928, 1929, 1930); Schuchert (**51**, 1927); and I. A. Keyte, W. A. Blanchard, and H. L. Baldwin (**32**, 1927).[2] For details the reader is referred to these papers.

The sequence is condensed in Table III, giving the principal correlations, according to the cited papers, supplemented by personal communications from E. H. Sellards, Powers, P. B. King, and Baker. The writer has visited the region on several occasions, sometimes in company with some of the authors mentioned.

The Permian sequence of the Glass Mountains is the thickest and most fossiliferous of any in North America, and being open marine, represents the key sequence for correlation of the American Permian with that which is developed elsewhere in the world.

OROGENY

Cheney, following Baker, suggests (**14**, p. 570) that the Marathon outcrops of Paleozoic rocks are connected with a southwesterly extension of the Ouachita system, and draws attention to the similarity

[1]Communication and map received from E. H. Sellards, as advance notice of a Texas report in preparation. See Sidney Powers, "Solitario Uplift, Presidio-Brewster Counties, Texas," *Bull. Geol. Soc. Amer.*, Vol. 32 (1921).

[2]After this paper had been written, the important new work by P. B. King was published by the University of Texas (**36**), which gives much new detail of the stratigraphy, as well as of the structure of the Marathon region. Through kind advance communications from the author, supplemented by advice from C. L. Baker concerning the Solitario area, the writer has been permitted to make use of such of the results of this work as pertain to our present problem. It thereby appeared that King had been reaching conclusions very similar to those of the writer. This similitude of opinions of two students, working entirely independently of each other, can be greeted as an excellent confirmation of the probability that these conclusions are correct.

of deposition and structural history. The writer has repeatedly expressed the same views in unpublished reports known to his collaborators. The problem is how these elements are connected. On this problem, Sellards, Cheney, and P. B. and R. E. King have recently performed and published valuable work.

TIME OF MARATHON OROGENIC PHASES

As the older Paleozoic sequence in the Marathon region, older than the Carboniferous, has been very severely folded and overthrust by later diastrophism, it is difficult to unravel the earlier tectonic history. We will not discuss these pre-Carboniferous phases further. They are more or less outside the scope of this paper. The time of the "Taconic" (Caledonian) orogeny may be represented by the hiatus between the Maravillas formation and Caballos novaculite, and the seemingly important orogenic break between the Maravillas and Marathon (Trenton) series. Not much is known about this interesting hiatus in the Ouachita Mountains, except that, seemingly, both the Arkansas novaculite and the Missouri Mountain slate are unconformable on the Blaylock, also approximately Richmond-to-Trenton in age (**18**, Plate XXV; also **58**).

WICHITA OROGENIC PHASE

The Tesnus overlies the pre-Carboniferous unconformably, with a basal conglomerate, indicating a pre-Tesnus erosion of the novaculite (**34**, p. 111). Unfortunately, fossils are almost absent, and many of the exposures are so poor and so complicated by structural disturbance, that the extent of the break is not well known. The Tesnus is a typical flysch-type deposit, and probably more than 4,000 feet thick in the southeastern angle of the Marathon basin,[1] although on the northwest it is found to thin progressively, dwindling to a thickness of only 225 feet in the region of the Roberts Ranch, southwest of the town of Marathon. This thinning is partly the result of overlap of the Tesnus on the Caballos formation, and the contact is nearly everywhere marked by a conglomerate in this region. There is, however, also a real thinning of the entire Tesnus formation toward the northwest, and the sediments very certainly had their source in the southeast. In the southeastern part of the basin, the Tesnus is nearly all sandstone, including thick ledges of white quartzite, and other layers of arkose and graywacke, with a chloritic matrix. In the northern part of the Marathon basin more than half of the formation consists of blackish shales, and its sandstone beds

[1]Powers measured 7,590 feet of Tesnus along San Francisco Creek (*Bull. Geol. Soc. Amer.*, Vol. 32 (1921), p. 423, footnote.

TABLE III[1]

Paleozoic Sequence in Marathon Uplift

Correlations			Thickness in Feet	Description
Cretaceous				Lower Cretaceous
				Great unconformity
Tartarian-Kazan Series. Higher Zones of Indian Productus Limestone, German Zechstein	Upper Permian	Double Mountain Series	0-720	Bissett conglomerate Limestones and coarse conglomerate, consisting predominantly of Glass Mountain dolomites
				Unconformity (overlap of 1,800 feet of strata)
			Circa 3,000	Capitan series (Tessey-Gilliam-Vidrio) Largely dolomite, grading northeast into Red-beds and anhydrite, with dolomites and rock salt deposits of saline series of West Texas
				? Slight unconformity indicated
Kungur Division. Lower Zones of Indian Productus Limestone	Lower Permian	Double Mountain Series	300-1,500	Word formation Cherty limestones, grading south into clastics (Del Norte Mountains); thinning northeast into 300 feet of cherty limestones in Sierra Madera, and finally grading into basal dolomite and sandstone series of Salt basin *Waagenoceras* zone
Artinsk Division of Russia		Clear Fork Series	300-1,800	Leonard formation Shales with thin limestones grading southwest into clastics, and northeast into featureless dolomite (300 feet) in Sierra Madera; finally grading into basal dolomites and limestones of Salt basin ("Big lime") *Perrinites vidriensis* zone
		Wichita-Albany Series	50-2,100	Hess formation Dark limestones, becoming dolomitic northeast, interfingering with vari-colored, partly red, marly, and sandy beds. Overlapping in the southwest on older formations. Coarse conglomerate at base *Perrinites compressus* zone
				Unconformity
			475-700	Wolfcamp formation Dominantly dark shales, thickening and becoming clastic southwest; overlapping on older formations *Uddenites* zone
				Perhaps great erosional unconformity, hiatus decreasing northeast: Arbuckle orogenic phase

[1]Revised by B. H. Harlton and F. A. Bush.

TABLE III—*Continued*

Correlations							Thickness in Feet	Description
					LOWER CISCO-CANYON	POW-WOW RED-BEDS OF HUECO MOUNTAINS	Max. 525	UPPER GAPTANK FORMATION Mainly limestones, intercalated with shales
PENNSYLVANIAN			STRAWN	HOXBAR OF ARDMORE		UPPER GRAY LIMESTONE OF HUECO MOUNTAINS		LOWER GAPTANK FORMATION Mainly shales, with interbedded limestones; more clastic and conglomeratic in lower part, containing fragments of all older Paleozoic rocks, notably Dimple and novaculite Fossils: Pennsylvanian assemblage, probably not older than Canyon "*Molasse.*" Generally less clastic and more marine than in Ouachita region
				DEESE OF ARDMORE BASIN				
			MILL-SAP	DORNICK HILLS		LOWER DARK LIMESTONES OF HUECO MOUNTAINS	2,000	HAYMOND FORMATION Sandstones, interbedded with green shales Plants and a few marine fossils
		BEND OF TEXAS						*No evidence of unconformity at Marathon. Upper pulsation of Wichita phase (not developed at Marathon)*
			(MORROW)	SPRINGER OF ARDMORE BASIN		LOWEST HUECO LIMESTONE WITH MORROW FAUNA	Circa 1,100	DIMPLE FORMATION Massive, very poorly fossiliferous limestones; cherts, shales, and conglomerates *Foraminifera* indicate lowest Pennsylvanian Bend = Morrow "*Flysch.*" Less clastic, more marine in upper part, than in Ouachita region
								Possible orogenic unconformity
MISSISSIPPIAN		JACKFORK-STANLEY SEQUENCE OF OUACHITA MOUNTAINS		CANEY OF ARBUCKLE REGION IN PART			Circa 3,500	TESNUS FORMATION Greenish sandstones and great thicknesses of blue, greenish, black, in many places siliceous shales; thin streaks of green cherts near base Poorly preserved plant remains, Pottsville age
								General unconformity: lower pulsation of Wichita phase
DEVONIAN (ORISKANY?)				ARKANSAS NOVACULITE IN PART		CHERTS IN FRANKLIN AND HUECO MOUNTAINS	More than 300	CABALLOS NOVACULITE White and varicolored chert beds Nearly unfossiliferous
								Important hiatus
	RICHMOND		BLAYLOCK BIGFORK			VIOLA	100 to more than 800	MARAVILLAS SERIES Dark gray alternating thin-bedded cherts and limestones; basal conglomerate
								Unconformity: possibly orogenic ("Taconic")
ORDOVICIAN		TRENTON	CIRCA 2,000 FEET OF BEDS IN VERY SIMILAR FACIES IN OUACHITA MOUNTAINS		LOWEST VIOLA		More than 375	MARATHON SERIES Yellowish shales and thin gray limestones Fossiliferous: lower Viola fauna
					SIMPSON?		Circa 500	Interbedded green, gray and black shales, and thin limestones
	MIDDLE CANADIAN			ARBUCKLE LIMESTONE OF OKLAHOMA			130	Dark gray, thin-bedded cherty limestone Fossiliferous: middle Canadian fauna *Phyllograptus* zone
							More than 300	Fine to coarse, partly conglomeratic sandstones, with greenish shales Few fossils
	UPPER OZARKIAN						300 to 500	Interbedded dark limestones and shales Fossiliferous: upper Ozarkian fauna
								Break in sequence
UPPER CAMBRIAN			CRYSTAL MOUNTAIN SANDSTONE?				Only 100 to 200 exposed ?	BREWSTER FORMATION Boureland Ranch locality and several other places are Chazy in age Flaggy brown sandstones, interbedded with dark green shales Fossiliferous: upper Cambrian fauna *Base not exposed: deeper parts of sequence not known*

are all of fine grain (*cf.* **36**, pp. 31-36 and 114). The Tesnus has also been identified at Solitario in the (Tesnus) Rough Creek shale, resting with an erosional unconformity on the Caballos novaculite.[1]

The exact age of the entire mass of either the Caballos novaculite or of the Tesnus formation, notably how far the latter may extend down into the Carboniferous, is not known. It may only represent the Strawn, but it is much more probable that a part of this thick orogenic sequence also includes both Morrow and highest Mississippian horizons. David White has stated that some of the scarce and poor plant remains collected near the top of the Tesnus suggest lowest Pennsylvanian (Pottsville) (**49**, p. 1066). P. B. and R. E. King also state that *Foraminifera*, also collected near the top of the Tesnus, according to B. H. Harlton, suggest lowest Pennsylvanian (**34**, p. 111). Thousands of feet of strata, whose age has never been established, underlie these fossiliferous horizons. P. B. King expressed the opinion that, not impossibly, the base of the Tesnus may be correlative with the upper part of the Helms formation, exposed in the Hueco Mountains, and that, therefore, at least in part, it could be highest Mississippian, and might well occupy a position on the foreland similar to that discussed in connection with the Arbuckle Caney (**32**, **34**, **39**, **51**). The upper Helms is also separated from the underlying Lower Mississippian part, or Lake Valley limestone, by a marked unconformity. It thickens and becomes more clastic toward the south (**36**, p. 36). Thus, we may conclude that the Tesnus might probably be correlative with the Ouachita Stanley, and the Parkwood of Alabama, and include most or all of the Jackfork. The Dimple, according to P. B. King, is probably Morrow, and according to David White, plant fossils from the Haymond formation belong to "some part of the Pottsville." The break at the base of the Tesnus might represent the same orogenic phase in the highest Mississippian as that described in connection with the Ouachita Mountains. The writer has named this *the older pulsation of the Wichita phase. This makes the Tesnus, and perhaps a part of the overlying older Pennsylvanian, the equivalent of the Caney-Springer sequence of the Ardmore basin, deposits which we have termed the flysch of the Ouachita Mountains.*

Like the Ouachita Stanley, the Marathon Tesnus and Haymond sediments are, in part, derived from crystalline and metamorphic rocks (**36**, pp. 34 and 42). *The Gaptank and highest Haymond conglomerates, on the contrary, are derived from the complete sequence of the older Paleozoic rocks exposed in the Marathon Mountains, including, notably, the post-*

[1]Communication from C. L. Baker.

Tesnus Dimple, in addition to the Caballos and Maravillas formations (**35**, p. 908). This makes these two groups of strata markedly different; evidently an important tectonic event separates them.

When discussing the Ouachita Mountains, the writer noted the absence of a marked break between the flysch and molasse groups in those mountains. Though there exist irregularities, possibly indicating a tectonic contact, there is no sign of an important angular unconformity between the Jackfork-Stanley flysch and the Atoka molasse formations in any of the exposures within the Ouachita Mountains. The second pulsation of the Wichita orogenic phase, which caused the change in the sediments, must have been located farther south.

Exactly the same condition seems to have existed in the Marathon Mountains. No break can be seen in the lower part of the Carboniferous sequence, though unconformity has been claimed for the base of the Dimple (Bend). According to P. B. King, the contact between the Dimple and the Haymond is gradational and seemingly conformable. The transition is well exposed in several places about 15 miles east of Marathon. The Gaptank also overlies the Haymond conformably. The basal member, the *Chaetetes* limestone, lies directly on thin-bedded Haymond sandstone (**34**, p. 114). The outcrop at Solitario gives no additional information, as no Pennsylvanian younger than upper Tesnus is represented here.

Although there is no unconformity in the sequence at Marathon, the facies seems to indicate the two pulsations of the Wichita orogeny more or less clearly. The clastic deltaic Tesnus formation is followed by the quiet period of limestone deposition represented by the Dimple (more or less equivalent to the Wapanucka), and this, in turn, is succeeded by a new thick series of clastic sediments, quite similar to the Tesnus, the Haymond, indicating the resumption of vigorous erosion. There even occurs in the highest Haymond a widespread layer of chert conglomerate. Evidently most of the Haymond must be considered as upper Pottsville and lowest Strawn; it is, therefore, to be correlated with the Atoka-Thurman sequence of the Ouachita Mountain region, and the Dornick Hills-Deese series of the Ardmore basin. The lowest Gaptank beds represent lower Strawn, and the entire Gaptank sequence extends into Canyon.

In the Marathon foreland, however, the dividing unconformity is in evidence, and we have seen the same thing in front of the Ouachitas, in the Ardmore basin in particular. It comes in at the end of Morrow time. In the Hueco Mountains, as well as in the Llano-Burnet exposures, we

find this same unconformity between beds of Morrow and of Strawn age (**35**, Fig. 2, p. 909).

Consequently, it is found that *both pulsations of the Wichita phase are in evidence in the Marathon Mountains:* the older late Mississippian pulsation is expressed by marked unconformity. The later post-Morrow pulsation is expressed, within the exposed part of the mountains, only by a marked change in the character of the sediments, but in the foreland it is expressed by actual unconformity. *All this is exactly similar to conditions in the Ouachita Mountains.*

ARBUCKLE OROGENIC PHASE

The late Pennsylvanian and Permian orogenic movements are far more clearly indicated in this western region than in any of the more easterly chains of the Ouachita system. The Arbuckle phase was very intense in these mountains, and affects strata which are better known in detail.

As in the Wichita system, the Arbuckle considerably obscures the earlier phases. It seems to begin in Cisco time. The most important break underlies the Permian Wolfcamp formation, and the hiatus comprises all the highest Cisco, and probably some of the lowest Permian. Baker places the more important orogenic unconformity at the base of the upper Gaptank. P. B. King does not agree with this opinion, but mentions other evidence that the first disturbances began as early as Canyon time, similar to what we have described before in connection with the Ardmore region. The Wolfcamp and Hess formations, and perhaps the Leonard, overlap southwestward over a land surface uplifted by the Arbuckle phase. Disturbance and reactivated erosion still continued during much of the Lower Permian. There is a general unconformity at the base of the Hess, with signs of active denudation near by and the formation of coarse conglomerate. Deposition of clastics continues in the Leonard. *These are subsequent pulsations of the Arbuckle orogeny.* Their prominence and duration emphasize the intensity of this phase in the southwestern region of the Mid-Continent.

Baker discovered the very significant fact that in the Marathon basin the pre-Pennsylvanian formations constitute a nappe, which has overridden the Upper Pennsylvanian beds from the south in a widespread flat overthrust, the Dugout Creek, or Peña Colorada thrust. The thrust is a horizontal, subsequently warped shear. The folds within the overthrust mass are cut off flat and have no relation to the structure in the autochtone. Later warping and erosion have caused a wide window in the northwestern part of the Marathon basin. East of the longitude of

TABLE IV

PRE-CARBONIFEROUS SEQUENCE IN SOLITARIO UPLIFT IN SOUTHWEST TEXAS
(After C. L. Baker)

General Age	*Description*	*Correlation with old Paleozoic Rocks of Marathon Region*
HIGHEST MISSISSIPPIAN ?	ROUGH CREEK SHALE	Tesnus
	~~ *Erosional unconformity* ~~~	~~~ *Wichita phase* ~~~
DEVONIAN ?	CABALLOS NOVACULITE Similar to Marathon development	Caballos novaculite
?	"SOLITARIO FORMATION" 15-50 feet of bright green siliceous and clay shales	?
	~~ *Hiatus (Taconic orogenic epoch)* ~~~	
UPPER ORDOVICIAN	MARAVILLAS CHERT Development as at Marathon, but relatively more chert and less limestone (Richmond-Fernvale age)	Maravillas chert
	~~ *Unconformity and break* ~~~	
MIDDLE AND LOWER ORDOVICIAN	MARATHON SERIES Trenton, Black River, Lowville, Chazy, and Beekmantown age: cherts, shales, limestones, some sandstones and conglomerates, corresponding with similar formations in Marathon region[1]	Marathon series Woods Hollow shale, Fort Peña formation, Alsate shale, Marathon limestone
UPPER CAMBRIAN	Marine fossiliferous, buff sandstones, drab shales, and some thin interbeds of impure limestones; in considerable part arkosic	Dagger Flat sandstone ?
PRE-CAMBRIAN ?	1. Much contorted marbles, with very narrow bands of chert, similar and possibly equivalent, to marbles with chert bands in region north of Eagle Flat and Allamore, and northwest of Van Horn, at the southern margin of Diablo Plateau (in Millican formation) 2. Quartzites, resembling somewhat pre-Cambrian quartzite of Franklin Mountains[2]	Not represented

[1]Represented in a very complex anticlinorium, on the nappe in the northern half of the Paleozoic area of the Solitario. This nappe is folded; erosion exposes windows of Rough Creek-Tesnus in the substratum, surrounded by Ordovician rocks.

[2]These metamorphic rocks are contained in another nappe, possibly thrust over the Cambro-Ordovician complex.

the town of Marathon there are no clear indications of the edge of the nappe. Several overthrusts have been mapped by King in the region between the Gaptank locality and the Tesnus railway station, but these seem more related to broken and overthrust anticlines and not to a true nappe. As this thrust is seen to override upper Gaptank (Cisco) beds, it can not be older than the Arbuckle phase, but it may be somewhat younger. Recently Baker has advised the writer that this same overthrust is in evidence at the Solitario uplift. Here we find Ordovician rocks in a nappe, which has also been warped and eroded, exposing the autochtonous substratum in erosional windows. The autochtone consists here of Rough Creek-Tesnus. In this more southern exposure, another very significant fact has recently been established, not known before, either at Marathon or in the Ouachita Mountains. At Solitario an extremely metamorphosed quartzite and contorted cherty marbles (resembling somewhat the quartzites of the Franklin Mountains and the Millican formation of the Diablo Plateau), have been found in another nappe, overriding the Cambro-Ordovician thrust sheet.[1] Baker considers these rocks pre-Cambrian. The writer points to the possibility that all or part of them may be metamorphosed Paleozoic formations. The discovery of this metamorphic interior nappe is in accordance with what we know from the structure of the southern Appalachians, and is additional proof of the great importance of the Marathon Mountain chain.

When discussing the Ouachita Mountain structure (*cf.* p. 1028), the writer called attention to the evidence that the final overthrusting of the Ouachita nappes was posterior to the Arbuckle phase in that region, and that the final paroxysm must have occurred after the highlands raised by the Arbuckle orogeny had been considerably peneplaned, possibly in mid-Permian time. It will be remembered that the writer came to the conclusion that the Arbuckle phase did not affect the Ouachita Mountains. In the Glass Mountains, on the contrary, we have conclusive evidence that the Dugout Creek overthrust was pre-Wolfcamp, in other words, that the thrusting was closely related to the Arbuckle phase, though it may have been its concluding stage. The oldest rocks exposed below the thrust plane are referred by King (foregoing paragraph) to the upper Haymond; they are overlain by the *Chaetetes* limestone of the basal Gaptank formation. The highest beds in the autochtonous substratum are upper Gaptank. The youngest beds exposed on the nappe, back of the thrust plane, are Haymond. Gaptank, so far, has not been identified on the overriding mass, which contains the complete

[1]Communication from C. L. Baker.

section of the pre-Gaptank Carboniferous and old Paleozoic rocks, as represented in this region. In this respect also the Marathon structure is similar to the Ouachita Mountains, where the youngest formation in the nappe is Atoka. The Haymond, however, is probably younger than the highest beds included in the intra-Ouachita Atoka. As no beds older than highest Haymond are exposed in the Marathon autochtone, we know nothing of their facies and development, or how far these differ from those on the nappe. It is possible that a well, drilled at the southern base of Dugout Mountain, in the autochtone, has reached the Dimple, after having pierced 1,700 feet of black and gray sandy shales of the Haymond (**36**, p. 42). At the Solitario the autochtone underlying this nappe is upper Tesnus. Consequently this overthrust overrides the entire Pennsylvanian (and probably some highest Mississippian flysch), including beds as high as the Cisco.

The first precursory movements of the Arbuckle disturbance are indicated in latest Haymond time by a thin layer of chert conglomerate. Deposition of coralline limestone followed again in the lower Gaptank, but anticlines soon began to rise in the geosyncline. Their erosion contributed boulders of Dimple limestone to the Gaptank conglomerates of the southern exposures. Here also there is similarity with southeastern Oklahoma. In the Ardmore basin, the Hoxbar also contains some conglomerate, indicating the Arbuckle Mountains as their source (**54**, p. 43). Although the Oklahoma Ouachita Mountains indicate no disturbance at this time, the Upper Strawn (Lower Hoxbar) Brazos River conglomerate of East Texas suggests activity farther south in these chains. The folding must have advanced progressively northward in the Marathon region, for it was not until early Upper Gaptank time that the folds had risen sufficiently in the extreme northwestern part of the present Marathon basin to contribute any sediments to that area. Fragments of Caballos and Maravillas chert appear also in these later conglomerates. The finer clastics of the Gaptank formation are considered by King as re-worked erosional products of the Tesnus and Haymond shales and sandstones. During the earlier phases of the disturbance the folding was essentially local, creating differentiated basins of deposition in the general geosyncline, as is shown by the variability in character of the Gaptank deposits in different parts of the Marathon basin and, in general, the deformation increases in intensity toward the south (*cf.* P. B. King, **36**, p. 51).

The basal Permian Wolfcamp formation extends unconformably over all the structures created by the Arbuckle orogeny. At the west end of the Glass Mountains, fossiliferous upper Wolfcamp, with 350-400

feet of coarse basal conglomerate, overlies the nappe of the Dugout Creek overthrust, having been deposited after the overthrust had been sufficiently warped, and thereafter eroded, to cause a window to be created in the pre-Carboniferous rocks of the nappe, in which the Gaptank autochtone was laid bare. In consequence, the Permian now rests indiscriminately on Maravillas, Caballos, and Gaptank rocks (**36**, p. 113). It is here, at a point 4½ miles S. 15° E. of Lenox Siding, that ammonoids of Cisco age were collected from Gaptank beds, directly beneath the Dugout Creek thrust plane. The lower (*Uddenites*) member of the Wolfcamp is not present in this western part of the Glass Mountains. Consequently, we can only place the advancing of the Dugout Creek nappe somewhere between Middle Cisco and Upper Wolfcamp for this region. The Lower Wolfcamp of the eastern Glass Mountains rests with seeming conformity on Gaptank, but King states that, at other localities in this same region, it lies in one place on Tesnus and elsewhere on Haymond, with the intervening beds missing (**36**, p. 49). As mentioned before, the presence of the nappe and the amount of overthrusting have not been determined for this eastern region.

The known minimum displacement of the Dugout Creek thrust is more than 6 miles, but, particularly in view of its presence farther south at Solitario, it must have been very considerably greater.

Somehow connected with the orogenic phase creating these overthrusts, seems the recently reported occurrence of exotic blocks in the Haymond. Further work will be required before these interesting erratics can be properly interpreted. It would be extremely interesting if these blocks proved to be true Marathon flysch exotics, similar to those that have been described from the flysch of the Ouachita Mountains.[1]

[1]In December, 1930, Philip B. King observed a horizon in the Haymond formation, containing pebbles, cobbles, and large blocks of extraneous origin. Later work by C. L. Baker and E. H. Sellards traced this horizon farther and blocks were discovered as large as 100 feet in length and 25 feet or more in thickness. The boulders are from several formations older than the Haymond, and include Dimple, Tesnus, Caballos, and smaller erratics from the Maravillas and even from pre-Cambrian sources (*Texas Univ. Bur. of Econ. Geol. News Letter*, January, 1931). A brief paper on these blocks was given by Philip B. King, C. L. Baker, and E. H. Sellards at the December, 1930, meeting of the Geological Society of America.

Sidney Powers wrote to the writer in March, 1931, that the very large blocks are all of novaculite, scattered along an upturned outcrop. Fairly large blocks, as large as 3 feet in diameter, of other formations, occur together with fine cherty conglomerates. The pre-Cambrian pebbles are rounded and squeezed, and may not belong to the same stratum as the large boulders. Some of the blocks are reported to be "glacially" scratched. In Powers' opinion, the strata in which these erratics are embedded belong to the Haymond. The limestone blocks contain upper Marble Falls (Bend) fossils, according to R. C. Moore, which would make them equivalent to the Dimple, or the Ouachita Wapanucka. These beds may be included in a nappe or slice, underlying the Dugout Creek overthrust. Powers believes that the entire deposit is a deltaic or beach formation.

PERMIAN DISTURBANCE

The movements which we have already mentioned from Wolfcamp to Leonard time, are the after-phases of the Arbuckle orogeny, gradually decreasing in intensity. The sequence in the Glass Mountains shows that the Permian sea advanced from the northwest toward the southeast upon the Marathon land, where movement continued spasmodically during most of the Permian. In consequence, the Permian shows baffling lateral variations in facies and also in thickness of the subdivisions, which it is difficult to explain by mere variation of conditions of sedimentation; they also indicate sharp differences in the amount of subsidence within the basin in which these rocks were laid down. King gives a stratigraphic diagram along the strike of the Glass Mountain range, which clearly illustrates these variations (**36**, Fig. 17, p. 52). Regardless of these differences, the entire exposed Permian, from the base of the Hess upward to well within the upper Permian salt series, seems conformable in the Glass Mountains. The unconformity of the San Angelo-Duncan beds, very widespread farther north and northeast, and even indicated in the Guadalupe Mountains in the northwest, does not seem to be represented by any angular break in the Marathon Permian. If, therefore, as Melton thinks, a major orogeny occurred in the Permian, and later than the Garber sandstone (equivalent to the Hess), it either has no equivalent in the Glass Mountains, or it must be represented by the basal unconformity of the Hess, which seems too early.

Very much later in the Permian, disturbance is, however, in evidence. On the northwestern side of the Glass Mountains, is a coarsely clastic deposit, the Bissett formation, which contains heavy conglomerates and unconformably overlaps the Capitan beds of the Permian. It overlaps approximately 1,800 feet of eroded strata. The conglomerates are associated with some red and buff shales, sandstones, and a few limestones. Well rounded pebbles and cobbles comprise all the limestones and dolomites of the Capitan sequence, and in the highest horizons some chert and quartzite, probably of Word age. B. H. Harlton identified ostracods as Permian; fossil plants have also lately been determined as of late Permian age.[1] This formation is overlain by the basal Cretaceous, with an angular unconformity, which proves that important uplift, if not a more serious orogeny, must have occurred.

Farther north, in the foreland, there exist unconformities at the base of the upper, "main" salt series, overlying the basal dolomites of the "Big lime," partly equivalent to the Capitan formation. The uncon-

[1]Communications from E. H. Sellards and F. H. Lahee.

formity is well indicated in the wells of the Big Lake oil field in Reagan County. In addition, minor unconformities exist within the salt series.

Subsequent to the Bissett phase, further folding again affected the strata, and, at least in the northwestern Glass Mountains, the strongest pre-Cretaceous warping seems post-Bissett. In areas near by on the northwest, where the Triassic is present, we have proof that this disturbance is, in part, pre-Triassic. In this entire region, however, these late foldings were confined to very slight undulating warping and tilting of the strata. Because, generally, even in the later Cretaceous and post-Cretaceous phases, the intensity decreases away from the mountains, the assumption seems justified that there was stronger orogeny farther southeast, where no Permian strata have been preserved to give any evidence of these movements (**36**, p. 88).

The importance of the Marathon Mountains, as part of a major structural feature, is indicated by many signs. The wide development of an early Pennsylvanian foredeep, and, farther out, of an early Permian foredeep, and the orogenic facies of the deposits filling these troughs; the asymmetric profile of these foredeeps, and the fact that the depression moved progressively outward from the mountain front in later Pennsylvanian and Permian times; the very great intensity and duration of the Arbuckle phase; and, finally, the important flat overthrusting of the Dugout Creek and of the Solitario nappes—these all indicate a major orogeny. It is the history of a large and important mountain chain (*cf.* **14**, Figs. 1-7). In 1927 Schuchert expressed the opinion (**51**, p. 389) that the Caballos Mountains (the hills of folded and overthrust novaculite outstanding from the Marathon plain) were "only local mountains of a minor order." The writer believes that this is contradicted by the aforementioned evidence. Everything seems to point to the probability that the Marathon-Solitario Mountains represent the southwesternmost visible extension of the greater Ouachita system, after it had swung around the buttress of the Llano-Burnet massif.

In the foreland of the mountains, that is, in the adjacent southern part of the great Salt basin, folds occur, which, at least to some extent, seem to represent the open folds of the foothills zone. They are especially pronounced in the Sierra Madera, and have become known in the subsurface throughout eastern Pecos County. The Sierra Madera was very strongly domed by a post-Comanche orogeny, but there is evidence also of intense folding before the Cretaceous. The subsurface structures in Pecos County strike east and west and affect the Upper Permian. The latest movements may be of post-Bissett age. Their

strike conforms to the presumable trend of the Marathon arc in this locality. Wells on these structures indicate considerable uplift of the pre-Permian formations. The 5,200-foot well of the Shell Petroleum Corporation, on the crest of the Fort Stockton uplift, was drilled through a section of 4,460 feet of sediments regarded as Permian, in which the Castile, Capitan, Delaware, Leonard, Hess, and Wolfcamp have been identified. This series, however, rests on basement rocks,—quartzite, and biotite schist. Approximately 100 feet of detrital material, consisting chiefly of red and green shale, with weathered limestone fragments, lie at the base of the sedimentary sequence (**30** and **36**, 1930).

In the region intervening between the Marathon exposures and the Llano-Burnet uplift, the saline series, including the basal dolomites ("Big lime"), is underlain by a very thick series of dark gray to black shales, with some limestones. This section is absent from the crest of the Fort Stockton structure, where it either was eroded off, or was never deposited. The very deep wells in the Big Lake oil field in southwestern Reagan County provide a good section for this region. Here the Upper Permian salt series continues to a depth of 3,500 feet. Its basal dolomite ("Big lime"), here 800-900 feet thick, is conformably underlain by the black shale series, which has an aggregate thickness of 4,500 feet. This rests with a marked angular unconformity on Ordovician rocks.

The age of the black shales is Upper and Middle Pennsylvanian, as determined by micro-fauna from the well cuttings. This probably includes beds of Cisco, Canyon, and upper Strawn age. There is some confusion about the determination of certain fusulinids, namely *Schwagerina*, in these beds, but recent investigation from outcrops reveals *Schwagerina* in beds of Middle Cisco age.[1] Though interesting, the problem is not of major importance for our discussion. The essential point is, that there exists an important foredeep here. The correct identification of the beds encountered in wells must determine whether the greater influence in causing this trough must be ascribed to the Arbuckle or to the Wichita orogenic phase. Evidently, whatever the age of the complete series of the black shale formation may prove to be, the Arbuckle phase has very strongly affected this immediate foreland, and caused foothills folds in front of the mountains, as is notably indicated at Fort Stockton. It is evident that a great thickness of basal Permian, as well as Pennsylvanian, is present in the foredeep of the buried Marathon chain, east of the Marathon basin outcrops, and that conditions here are very similar

[1]Communication from B. H. Harlton, Amerada Petroleum Corporation, and F. A. Bush, Sinclair Oil and Gas Company, Tulsa, Oklahoma.

to those in the other region affected by both the Wichita and Arbuckle orogenies, the Ardmore-Anadarko basins.

Farther west, conditions in the foreland have revealed several uplifts caused by late Pennsylvanian and Mesozoic movements connected with the ancestral and the final Cordillera. In the Chinati Mountains an uplift has exposed conditions connected with the Permian foredeep, again showing the development of a thick series of black shales in the Hess and Wolfcamp periods (Udden, **56**, 1904; and Baker, **4**, 1929). Farther north, in the Wiley, Eagle, Van Horn, and Hueco Mountains, the influence of the Marathon chains is lost. The bulk of the sequence is now massive marine limestone, of Permian and Pennsylvanian age.

BURIED ELEMENTS OF OUACHITA SYSTEM

Recently available subsurface information permits the tracing, with considerable certainty, of the buried part of the Ouachita chains, at least the farther continuation of their *outer front*, throughout eastern Texas. This is made possible by the correlation of the sections revealed in hundreds of wells drilled throughout this region. Present knowledge has been fostered by the work of Sellards, Cheney (**14**, **15**, 1929), and Dott (**21**, 1927), not to mention many others who have assembled and coördinated all these data into a picture which now makes it possible to connect the visible Ouachita Mountains with the area on the southwest.

The central parts of the chains, however, south of the outcrops in the Ouachita Mountains, as well as their eastern continuation in the direction of Mississippi River, remain very obscure. Their possible connection with the Appalachians is not free from problems. *The Appalachians present the Wichita facies, and not the Ouachita facies*, throughout the entire Ordovician, Silurian, Devonian, and much of the Mississippian sequence. On the contrary, in the southernmost section, in Alabama, the development, from latest Mississippian time (Parkwood formation), shows the same flysch type, succeeded by the Pennsylvanian molasse type of sedimentation, as in the Ouachitas. So it seems that the Wichita geosyncline, rather than that of the Ouachita Mountains, is connected with the Appalachians, or that somewhere in the Mississippi embayment the two geosynclines come together and unite in the Appalachian system.

The conclusions outlined here as to the buried elements of the Ouachita system in eastern Texas are almost exclusively the result of analysis of the geologic history of late Paleozoic sedimentation in this region. The mountains themselves have scarcely been reached by drilling. It is necessary to reconstruct their nature and their course, and the phases of

the orogeny which built them, from their effects on the sedimentation and paleogeography of the region. These problems in particular have been the subject of the authors cited. Cheney gives a valuable map and cross sections of the subsurface in central Texas (**15**, Plate VII).

LOWER PENNSYLVANIAN FOREDEEP IN EAST TEXAS

Cheney's maps (**14** and **15**) are the first to describe clearly the distinct foredeep developed in central Texas during the Lower Pennsylvanian (A. I. Levorsen, **39**). This is an exact replica of the foredeep in the Oklahoma and Arkansas coal basin.

It has been shown that the early Pennsylvanian in front of the Marathon Mountains, and to an even more pronounced extent, in front of the Ouachitas, is characterized by a great deposit of detritus, originating from a renewed emergence in the mountains, evidently the result of a new active process of folding and uplift in the central chains, and depressing the new foredeep, farther out from the mountains and well in front of the trough in which the late Mississippian-Morrow flysch was deposited. This orogenic Pennsylvanian is here called the Ouachita molasse. Its source is the second pulsation of the Wichita phase. *The drill has revealed the existence of an entirely similar foredeep in east-central Texas.* No Lower Pennsylvanian is known to the writer in northwestern Texas or in western and northwestern Oklahoma. The Morrow sediments have still a comparatively wide spread; those of the lowest Strawn are very much more restricted (**49**, **21**).[1] The Strawn formation increases eastward from approximately 1,000 feet in western Throckmorton County, to 3,500 feet in Palo Pinto County, and (by interpolation, because the top has been eroded under basal Cretaceous) to 6,500 feet in eastern Parker County and 8,000 feet in central Coryell County (**14**, **15**). This increase in thickness is due partly to thickening of the Upper Strawn, but in addition, to the appearance of successively lower members of the Pennsylvanian sequence, on the east (Millsap formation) between the Bend and the Strawn.

The Millsap and Strawn not only thicken toward the east inTexas, but also, through their physical development, indicate an eastern source of the sediments. The Lower Strawn is still somewhat arkosic, as are the early Pennsylvanian beds in the Oklahoma coal basin, though the feldspars become less common, and a new material, chert, comes progressively into evidence. This indicates that the same changes occur in the source

[1]Equivalents of the Cherokee and Marmaton formations spread farther, and have been identified both in northwest Texas and western and northern Oklahoma.

region as are indicated for the Ouachita and Marathon mountains (Cheney, **14**, p. 572). Much chert conglomerate in the Middle and Upper Strawn, becoming coarse eastward, and grading into normal sandstones westward, proves the presence of chert rocks, in other words, of the Ouachita facies, subject to erosion farther east or southeast.

The presence of an open fold zone is also indicated in eastern Texas. Distinct folds, with northeast-southwest axes, are observed in north-central Texas. These affect strata nearly as late as the close of Strawn time; in other words, their time of folding is quite similar to that of the foothill folds in the Ouachita coal basin. Consequently, there is an ample supply of facts to afford assurance that an entirely typical foredeep develops here in the subsurface, and that it occurs as the result of a progressive overlap from the east over a sinking trough in the foreland.

It has been shown that, farther southwest also, Lower Pennsylvanian, as well as, probably, highest Mississippian, are encountered, in orogenic facies, in the Tesnus-Gaptank basin. These sediments also thicken within a short distance toward the mountains in the south, reaching a thickness ranging from 5,000 to 10,000 feet near the Rio Grande (Cheney, **14**, p. 565). These Texas basins have been made very obvious by Cheney on isopach maps for the Lower Pennsylvanian (**14**, Figs. 2 and 3). Their perfect alignment and similarity with the Oklahoma-Arkansas coal basin clearly indicate a common cause, and outline the course of the front of the chains of the Ouachita system. The basin of early Pennsylvanian deposition must sweep around the southeastern side of the Llano-Burnet massif. Certainly no Strawn was ever deposited in parts of Concho and McCulloch counties, northwest of the uplift. Cheney mentions the existence of a positive element striking northwest and southeast, extending northwest of the massif, which he names the Concho divide, an arch culminating in the Llano-Burnet uplift. The arch follows the ancient trend, which is expressed clearly in the basement rocks exposed in the Llano-Burnet region. The Concho axis and the Llano-Burnet uplift interrupt the regular development of the foredeep, in a manner similar to that of the Arbuckle massif farther north.

Southwest the importance of the Llano massif is shown by the sweep of the Balcones fault zone around it, turning to west-southwest in Bexar, Medina, and Uvalde counties. This is the rim-fault zone of the Gulf Coast depression. Back of the described foredeep in East Texas, a short distance west of the Balcones fault zone, wells have actually encountered the Paleozoic formations of the mountain front. Very recently Sellards has assembled the records of these wells in an

unpublished map. They extend in an unbroken belt, from Red River in the north, to Medina County in the south. The western front line extends through Grayson, Dallas, McLennan, Bell, Williamson, Travis, Hays, Kendall, and Medina counties. The rocks are evidently in Ouachita facies, entirely distinct from the foreland facies of East Texas, encountered in innumerable wells farther west. Graptolites have been secured from several of the samples, permitting the identification of some of the Ouachita horizons, notably Stringtown shale and Womble. Miser also identified Stanley. Most of the rocks in these wells have been referred to as "metamorphics" of "pre-Cambrian" age. According to Sellards, however, the only location that may have yielded pre-Cambrian rocks is in the Luling oil field in Caldwell County, a well far back from the front zone. The formations encountered farther west in southern Val Verde and Terrell counties, are also in Ouachita facies, extending the mountain front toward Marathon. These formations, however, are still of doubtful age.[1] As in the Ouachita Mountains, and at Marathon, the front zone, therefore, evidently consists of non-metamorphic old Paleozoic rocks in the Ouachita facies, and the difference in facies is as sharp as in the outcrops. Notably in Coryell, Burnet, Blanco, and Kendall counties, Sellard's map shows wells in the two facies within a distance of only a very few miles. The metamorphic rocks are encountered only farther back. They can not be identified from any exposures either at Marathon or in the Ouachita Mountains. But they have been known from a small outcrop at Boquillas in southwest Texas, from a locality on the opposite side of the Rio Grande in Mexico, and were lately identified by Baker in the Solitario, with the additional interesting discovery that they constitute another higher nappe, overriding the Dugout Creek thrust sheet. They may be present also in the well farthest east of those in Caldwell County. These facts are in accordance with what we find in the southern Appalachians, in Alabama.

Whatever may be the detailed structure of the front, *it seems evident that the Ouachita range has been encountered in the subsurface of East Texas, closely associated with the belt of the Balcones faults.*

HINTERLAND

Prevailing American opinion has always considered both the Appalachians and the Ouachitas as mountains that have risen out of intracontinental geosynclines. According to this view, which has been advocated particularly by Schuchert, and followed in nearly all the literature

[1]Communication from E. H. Sellards.

the hinterlands of these mountains would have been the "borderlands" *Appalachia* and *Llanoria*.[1] This interpretation seems justified for the Appalachians, notably for the northern Acadian part of this great mountain complex, but it is questionable whether it also holds for the Ouachitas. *Does Llanoria exist at all*, if we view it as an ancient rigid block in the earth's crust, acting first as a source region of the clastic flysch sediments, and, subsequently, as a vise jaw relative to the Ouachita geosyncline? In the writer's opinion, the chains of the Ouachita system have risen out of another, far more important type of geosyncline, a major inter-continental depression of the crust, the kind which Schuchert has described as a mediterranean geosyncline. In this case, the masses back of the very wide geosynclinal region would be a far greater crustal block, belonging to another continental unit, and the immediate hinterland of the exposed frontal chains would merely represent the more central metamorphic and crystalline zones of the very complex system of ranges generated in a geosynclinal area of this nature.

In a major mountain complex of this magnitude, the original geosyncline was never a simple trough, but a complex geosynclinorium. Several distinct troughs are separated by ridges, which themselves are either beginning anticlinoria or even embryonal thrust sheets, or, not uncommonly, older massifs, truncated horsts, left from some older orogeny, entirely foreign to the later structure, acting as independent, passive subordinate nuclei. Such a mountain complex thereby becomes very wide. The Variscan system of Europe, where a structure of this nature is clearly in evidence, has a present width of approximately 800 miles, and the width of the original geosyncline must have been at least 1,200 miles, before it was shoved together. The chains of the anticlinoria surround the passive subordinate nuclei, and the entire geosynclinal area is being deformed by the complex activity of the controlling continental blocks, forces which may be alternately compressive and expansive, as exposed in the theory of R. Staub (**53**). Though the geosyncline is subject to compression, "ground folding" (*plissement de fond*, as described by E. Argand) may be a considerable factor, as distinguished from superficial "cover folding" (*plissement de couverture*). Ground folding may, in particular, be the initial phase, creating the primary geosyncline and the elevated hinterland. Unlike the cover folds, the ground folds move much greater weights, with a far greater expenditure of energy; this is shown by the greater breadth and radius of curvature. The ground folds,

[1]The name Llanoria was derived from the Llano uplift, which was originally conceived as an exposed part of the borderland. It has been shown that this massif is no part of the hinterland at all, but of the foreland of central Texas.

not uncommonly, develop into particularly far-reaching horizontal displacements of major blocks, also on a larger scale than the superficial cover-overthrusts. Argand named these ground thrusts *charriages à sec* (dry overthrusts). Much of the initial upwarping of the hinterland, back of a nascent major geosyncline, may be structure of this nature. The older a mountain system is, the greater is the chance that erosion has reached down into levels where primary ground thrusts have been bared, especially when subsequent gravity compensations have caused regional uplift of the entire structure.

In this manner, bundles of great ranges, in many regions encompassing more inert, comparatively undeformed, older nuclei (*Zwischengebirge*), come into existence in an inter-continental geosyncline of great magnitude, the original extent of which was of oceanic width. When the entire region has been shoved together, various basins of deposition may become superimposed in different nappes, the travelling blocks having transported on their backs differentiated facies of stratigraphical sequences, although in age they may be more or less equivalent.

The primary continental blocks themselves, outside of the geosyncline, are only relatively more rigid. They also are deformed, warped, broken, and shoved, when forces of this magnitude act on the relatively thin crust. Notably near the margin of the continents, accidentally present preëxisting zones of relative weakness may be compressed into intra-continental subordinate mountain systems, which, however, are only counter-coups of the ma or events which occur in the inter-continental expanse.

The Wichita mountain system is a beautiful illustration of a large anticlinorium, squeezed and blockthrust out of an intra-continental geosyncline. The front of the Rocky Mountains has the appearance of the front of an intra-continental ground thrust, which moved at several periods, without ever evolving into a great folded chain, probably through the lack of a sufficiently thick and pliable sedimentary blanket deposited in a preëxisting geosynclinal depression.

The pelagic facies of the old Paleozoic rocks of the Ouachitas, the great compression of these chains, and the intensity of overthrusting, seem to postulate sufficient importance for the entire system to justify considering it as the frontal element of an inter-continental mountain complex. Its general location, trend, and relationship to what must have been the Paleozoic Tethys in these regions, support this supposition. The Wichitas, on the contrary, were formed out of rocks in the same epeiric facies as prevails over the whole plateau; the sequence is merely

considerably thicker. The old Paleozoic rocks of the Ouachitas are of a strikingly different type. These cherts and graptolite-bearing siliceous shales, and minor dark limestones, do not necessarily imply abyssal depths, but they are off-shore, oceanic sediments. The true hinterland was originally far removed, and must belong to the continental complex generally known as the Paleozoic Gondwana block. A very complicated system of anticlinoria, ridges and chains, and probably ancient *zwischengebirge*, must now fill the original geosyncline, generated by its late Paleozoic compression stage. Since then, complete abrasion and renewed sedimentation, and several phases of, possibly, almost equally important later orogenic cycles, have obscured the original structure. A period of expansion has succeeded the original compressive stage, and has created wide sunken basins of mediterranean magnitude in the Mesozoic era (the Mesozoic Tethys). In the late Cretaceous and the Tertiary, a new compressive movement began in a part of this new Mesozoic geosyncline. This was related to the Alpine revolution. This stage was again followed by renewed tension and down-warping. In America, in addition, the Laramide revolution of the Cordilleran system crossfolded the western region of the Tethys. The result of these great revolutions of world-wide extension is the complex regional structure of the present central America. The immediate result in the area which interests us here is the formation of the Gulf Basin and the adjacent Coastal Plain, extending northward into the Mississippi embayment. The basin deposits now obscure the entire hinterland and most of the frontal chains of the Ouachita system in its widest sense.

We may, therefore, expect that south of the exposed, or otherwise known frontal chains of the Ouachitas, including the Marathon Mountains and probably the southern Appalachians, a *very wide* hinterland zone exists, consisting of many and probably complex ranges, encircling some older massifs. This entire structure has broken down; after peneplanation, it subsided into early Mesozoic or possibly late Paleozoic (Permian?) intra-montane basins. The whole was covered later by the thick mantle of later Mesozoic near-shore sediments of the Tethys.

The Gulf Coast basin is already a coastal shelf part of the Tethys. The oldest definitely known strata are Lower Cretaceous. They have a great thickness, though far less than orogenic dimensions. The thickness certainly exceeds 4,000 feet in northern Louisiana, and possibly is greater in the more central area. We know that Lower Cretaceous, in a Tethyc facies, is largely developed in most of Mexico. It is mostly composed of flaggy and marly limestones, alternating in places with calcareous shales

and some heavy *Rudistes* limestones. On the Gulf Coast, the Lower Cretaceous grades into a great thickness of more near-shore, partly lagunal deposits, and upward into Upper Cretaceous and Tertiary. These sediments thicken toward the south, and on the Gulf Coast the entire sequence must exceed 15,000 feet (according to D. C. Barton).

A very long time intervened between the late Carboniferous and the deposition of the Lower Cretaceous. Of what happened in this time interval on the Gulf Coast, extremely little, if anything, is known.

OUACHITA SYSTEM AS A WHOLE

Concluding the foregoing discussion of the several provinces within the great Ouachita system, in its wider sense, and of the general foreland, we may now present the following comprehensive picture.

The Ouachita system is one of the earth's major orogenies. We know only its frontal part, composed of older Paleozoic rocks. This front can be traced from central Arkansas, through southeastern Oklahoma and central Texas, to the Rio Grande in the southwest. Presumably the chains are connected, east of the Arkansas outcrops, in the subsurface, with the Appalachians of Alabama.

The central, certainly crystalline ranges are entirely unknown; they are behind the exposed parts of the front, and the hinterland has everywhere subsided beyond any means of direct observation.

The northern loop of the Ouachita front overran the Wichita ranges. These were formed, and considerably peneplaned and buried, before the final paroxysm of overthrusting occurred in the Ouachita front. Certain ridges, however, must have stood out in relief in the autochtone of the western Ouachitas of Oklahoma, yielding tectonic exotic Wichita-facies blocks ("Caney boulders") in the overthrust nappes.

In south-central Texas the Ouachita front swings around the foreland buttress of the Llano-Burnet uplift, a massif of pre-Cambrian basement rocks, showing old pre-Carboniferous northwest-southeast axes, a trend which is maintained in the Concho Divide farther northwest.

From here the Ouachita system resumes a westerly-to-southwesterly trend, through the Marathon Mountains and beyond in the Solitario. From here the Ouachita chains are lost under the Cordillera.

The great northern loop in Oklahoma and Arkansas is somewhat astounding, particularly as it swings so close to the great buttress of the Ozark massif. This, to the writer, emphasizes the major importance of the ancient Hunton arch. So do the uplifts of the Arbuckle Mountains and the emergence of the Criner Hills.

It seems to the writer that the drifting and sliding masses of the Ouachitas were dammed back by the Hunton obstacle, and only east of it were able to push past, thereby forming this great northward lobe. The previous upthrust of the considerable competent mass of the Arbuckle massif, which antedated the overthrusting of the Ouachitas, must have increased the buttress effect of the Hunton arch.

The Bend arch and the Llano uplift follow more or less the same alignment toward the south, and may form a southerly continuation of the basement feature, or at least of a closely related *en échelon* counterpart. The entire region is crossed by the ancient north-south basement grain, of which the Hunton axis is one of the principal features; the uplift and emergence of the Criner Hills prove the southern continuation of this element beyond the Arbuckle Mountains. The shallow depth at which old rocks are encountered in the subsurface on the Muenster arch in Cooke County (pre-Mississippian at 1,450 feet) is an additional suggestion that the Hunton axis continues farther south (**15**, Plate VII).

One thing is evident: the north-northeast and south-southwest subsurface line of overthrusting, which marks the buried front of the Ouachita chains in this region, closely follows the eastern flank of this old axis in the basement, and the Balcones fault zone continues to follow the same strike. Cheney wishes to substitute the term Bend "flexure" for Bend "arch," because he believes that this swell was not caused by any uplifting, but merely by westward tilting of the originally eastward-dipping monocline, which was developed toward the foredeep in Strawn time. The writer acknowledges that this influence of Permian tilting westward, toward the depression of the Salt basin, is a factor, but he also believes, nevertheless, that the hinge was destined to occur at this particular location and in this strike, because of the old grain in the basement and a very ancient positive element, similar to, if not identical with, the Hunton axis.

Another indication is the very prominent uplift of the Llano-Burnet massif, along this same strike, where the Concho axis crosses the latter. This important massif, which acted as a sufficiently resistant buttress to deflect the entire course of the Ouachita chains, seems clearly to indicate that a much more important primary cause existed in the underlying floor. The Llano uplift is not *caused* by the pressure of the Ouachita chains against the Concho axis, since it was not deformed along Ouachita trends, as the open foothills folds, and as the Arbuckles were affected by the Wichita push on the Hunton arch. All the Ouachita onslaught may have done to the Llano-Burnet massif was, possibly, an accentuation

of the uplift with some north-northeast faulting. In the same manner the pressures which caused the folding of the Wichita chains may have accentuated the bulging of the Concho arch in a similar strike.

In successive phases two Paleozoic pushes have been shown at work in this entire region, acting almost at right angles to each other: the Wichita pressure toward the northeast and the Ouachita pressure toward the northwest. The Marathon chains, though still folded with a northeast strike in the part of the arc exposed at Marathon, show a somewhat intermediate action. These two strikes, in the opinion of the writer, are the components of a generally northward creep against the comparatively narrow southern end of the old rigid block of the North American continent. The region here considered is at the southern extremity of this wedge-shaped spur. The Appalachian forces pressed against its southern side. On its now much more indistinct western flank, forces are in evidence which have pressed eastward during almost the entire history of the continent, from, possibly, pre-Cambrian time to the present. They have thereby so crushed and involved the western margin of the old nucleus by later deformations as to have obliterated all sufficiently distinct traces of the old continental border west of the Wasatch range of Utah.

The repeatedly mentioned two major directions in the old grain are in accordance with this general conception. The predominant north-south ridges in the granite basement have generally a fault scarp on their eastern side, which may well be an ancient thrust fault at depth, indicative of an eastward pressure as early as in pre-Cambrian time.

It seems, therefore, permissible to consider the major Ouachita system, together with the Appalachians, as part of the great belt of late Paleozoic chains that almost encircles the world: the great southwestern branch of the Variscan Altaids, passing along the southern end of Laurentia. The Ouachitas, in particular, form an arc, pressing against the southeastern side of this wedge-shaped nucleus.

The Wichita system is only an intra-continental counter-coup of the Paleozoic northward creep against the southwestern side of the wedge. The main system of this western component of the south-to-north pressures, out from the continental border, is unknown. It probably lies hidden in the Paleozoic basement, much broken and overrun by the repeated phases of the Cordilleran system out from the Pacific. This latter is a creep entirely different from the pressures here discussed.

Certain trends in Utah and Arizona, in the Mohave Desert of California, the San Bernardino Spur, and even the configuration of the Pacific shelf off Cape Conception, may be suggestive for speculation.

The Wichita counter-coup affected only a zone of weakness, caused by a preëxisting intra-continental old Paleozoic geosyncline, which had escaped compression when elsewhere in the world the pre-Devonian orogenic cycle was active. When the late Paleozoic northward push abutted against the southern extremity of Laurentia, the Wichita geosyncline gave way and was squeezed into folds and block-faulted uplifts. Afterward it was partly overrun by the oncoming thrust sheets of the Ouachitas in the latest phases of the Paleozoic cycle.

Immediately after the diastrophism, the central zones of the great chain broke down and subsided, as has happened almost regularly in all major orogenies of the earth. Only certain frontal fragments of the great chain remained standing as horsts. The Ouachitas seem to have been broken down more than the Appalachian branch, and the latter was more strongly rejuvenated by the Cretaceous-Tertiary Alpine cycle, events in which, possibly, the (younger) Atlantic was a factor.

The survival of the great mountain front of the Ouachitas in Texas, as an active, though deeply buried element, in much later geologic history of the region, is proved by the striking parallelism of the Balcones fault zone, along the same strike, only 10 miles farther east. This parallelism is maintained from Arkansas to the Mexican border. That it should be exactly along this strike that the Cretaceous-Tertiary gulf basin subsided, is extremely suggestive.

BIBLIOGRAPHY

1. F. L. Aurin, G. C. Clark, and E. A. Trager, "Notes on the Subsurface Pre-Pennsylvanian Stratigraphy of the Northern Mid-Continent Oil Fields," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 5, No. 2 (March-April, 1921), pp. 117-53.

2. Charles L. Baker and W. F. Bowman, "Geologic Exploration of the Southeastern Frontrange of Trans-Pecos Texas," *Texas Univ. Bull. 1753* (1917).

3. Charles L. Baker, "Exploratory Geology of a Part of Southwestern Trans-Pecos Texas," *Texas Univ. Bull. 2745* (1927).

4.———, "Note on the Permian Chinati Series of West Texas," *Texas Univ. Bull. 2901* (1929), pp. 73-84.

5.———, "Depositional History of the Redbeds and Saline Residues of the Texas Permian," *Texas Univ. Bull. 2901* (1929), pp. 9-72.

6. Clyde M. Becker, "Structure and Stratigraphy of Southwestern Oklahoma (Wichita Mountains)," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 14, No. 1 (January, 1930), pp. 37-56.

7. J. W. Beede and D. D. Christner, "The San Angelo Formation and the Geology of Foard County, Texas," *Texas Univ. Bull. 2607* (1926).

8. E. Blackwelder, "A Summary of the Orogenic Epochs in the Geologic History of North America." *Jour. Geol.* (1914), p. 633.

9. George C. Branner, "Geologic Map of Arkansas," *Arkansas Geol. Survey* (1929).

10. E. Böse, "Permo-Carboniferous Ammonoids of the Glass Mountains," *Texas Univ. Bull. 1762* (1917).

11. H. Böttcher, "Die Tektonik der bochumer Mulde zwischen Dortmund und Bochum und das Problem der westfalischen Karbonfaltung," *Essener Gluckauf*, No. 37 (1925).

12. J. R. Bunn, "Oil and Gas in Jefferson County, Oklahoma," *Oklahoma Geol. Survey Bull. 40 PP* (1930).

13. L. D. Cartwright, Jr., "Transverse Section of the Permian Basin of West Texas and Southeastern New Mexico," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 14, No. 8 (August, 1930), pp. 969-82.

14. M. G. Cheney, "History of the Carboniferous Sediments of the Mid-Continent Oil Field," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 6 (June, 1929), pp. 557-94.

15.———, "Stratigraphic and Structural Studies in North-Central Texas," *Texas Univ. Bull. 2913* (1929).

16. S. K. Clark and J. I. Daniels, "Relations Between Structure and Production in the Mervine, Ponca, Blackwell, and South Blackwell Oil Fields, Kay County, Oklahoma," *Structure of Typical American Oil Fields*, Vol. I (Amer. Assoc. Petrol. Geol., 1929), pp. 158-75.

17. L. W. Collet, *The Structure of the Alps* (London, 1927).

18. Carey Croneis, "Geology of the Arkansas Paleozoic Area," *Arkansas Geol. Survey Bull. 3* (1930).

19. C. L. Dake, "The Problem of the St. Peter Sandstone," *Bull. Missouri School of Mines* (1921), p. 55.

20. N. H. Darton, *Geological Map of New Mexico* (U. S. Geol. Survey, 1928).

21. R. H. Dott, "Pennsylvanian Paleogeography with Special Reference to South-Central Oklahoma," *Oklahoma Geol. Survey Bull. 40 J* (1927).

22. A. J. Freie, "Sedimentation in the Anadarko Basin," *Oklahoma Geol. Survey Bull. 48* (1930).

23. F. Gouin, "The Geology of the Oil and Gas Fields of Stephens County, Oklahoma," *Oklahoma Geol. Survey Bull. 40 E* (1926).

24. Charles N. Gould, "The Correlation of the Permian of Kansas, Oklahoma, and North Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10, No. 2 (February, 1926), pp. 144-53.

25. M. A. Hanna, "An Interesting Volcanic Ash from Calcasieu Parish, Louisiana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10, No. 1 (January, 1926), pp. 93-95.

26. M. C. Hoffman, "Geology and Petrology of the Wichita Mountains," *Oklahoma Geol. Survey Bull. 12* (1930).

27. C. W. Honess, "Geology of the Southern Ouachita Mountains of Oklahoma," *Oklahoma Geol. Survey Bull. 32* (1923).

28.———, "Geology of Atoka, Pushmataha, McCurtain, Bryan, and Choctaw Counties, Oklahoma," *Oklahoma Geol. Survey Bull. 40 R* (1927).

29. J. Harlan Johnson, "Contribution to the Geology of the Sangre de Cristo Mountains of Colorado," *Proc. Colorado Sci. Soc.* (1929).

30. E. L. Jones and Russell C. Conkling, "Basement Rocks in the Shell-Humphreys Well in Pecos County, Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 14, No. 3 (March, 1930), pp. 314-16.

31. F. E. Kendrick and H. C. McLaughlin, "Relation of Petroleum Accumulation to Structure in Petrolia Field, Clay County, Texas," *Structure of Typical American Oil Fields*, Vol. II (Amer. Assoc. Petrol. Geol., 1929), pp. 524-55.

32. I. A. Keyte, W. A. Blanchard, and H. L. Baldwin, "The Gaptank-Wolfcamp Problem of the Glass Mountains, Texas," *Jour. Paleont.*, Vol. I (1927), pp. 175-78.

33. Philip B. King, "The Geologic Structure of a Portion of the Glass Mountains of West Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10, No. 9 (September, 1926), pp. 877-84.

34. Philip B. and Robert E. King, "The Pennsylvanian and Permian Stratigraphy of the Glass Mountains," *Texas Univ. Bull. 2801* (1928), pp. 109-45.

35.———, "Stratigraphy of the Outcropping Carboniferous and Permian Rocks of Trans-Pecos Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 8 (August, 1929), pp. 907-26.

36.———, "The Geology of the Glass Mountains," *Texas Univ. Bull. 3038* (1930).

37. K. Lehmann, "Das tektonische Bild des rheinisch-westfalischen Steinkohlengebirges," *Essener Gluckauf*, Nos. 1, 2, and 3 (1920).

38.———, "Das rheinisch-westfalische Steinkohlengebirge als Ergebniss tektonischer Vorgange in geologischen Trogen," *Essener Gluckauf*, No. 15 (1920).

39. A. I. Levorsen, "Pennsylvanian Overlap in United States," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 15, No. 2 (February, 1931), pp. 113-48.

40. H. W. McClellan, "Subsurface Distribution of Pre-Mississippian Rocks of Kansas and Oklahoma," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 14, No. 12 (December, 1930), pp. 1535-56.

41. F. A. Melton, "Age of Ouachita Orogeny and its Tectonic Effects," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 14, No. 1 (January, 1930), pp. 57-72.

42. H. D. Miser, "Llanoria," *Amer. Jour. Sci.*, Vol. 2 (1921), pp. 61-89.

43.———, "Geologic Map of Oklahoma," *U. S. Geol. Survey* (1926).

44.———, "Structure of the Ouachita Mountains of Oklahoma and Ar-Kansas," *Oklahoma Geol. Survey Bull. 50* (1929).

45. H. D. Miser and C. W. Honess, "Age Relations of the Carboniferous Rocks of the Ouachita Mountains of Oklahoma and Arkansas," *Oklahoma Geol. Survey Bull. 44* (1927).

46. H. D. Miser and A. H. Purdue, "Geology of the DeQueen and Caddo Gap Quadrangles, Arkansas," *U. S. Geol. Survey Bull. 808* (1929).

47. Raymond C. Moore, "Correlation of Pennsylvanian Formations of Texas and Oklahoma," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 8 (August, 1929), pp. 883-902.

48. G. D. Morgan, "Stratigraphic Position of the Frank and Seminole Formations of Oklahoma," *Oklahoma Geol. Survey Cir. 12* (1923).

49. Sidney Powers, "Age of the Folding of the Oklahoma Mountains; the Ouachita, Arbuckle and Wichita Mountains of Oklahoma and the Llano-Burnet and Marathon Uplifts of Texas," *Bull. Geol. Soc. Amer.*, Vol. 39 (1928) pp. 1031-72.

50. F. B. Plummer and R. C. Moore, "Stratigraphy of the Pennsylvanian Formations of North-Central Texas," *Texas Univ. Bull. 2132* (1921).

51. Charles Schuchert, "The Pennsylvanian-Permian of Western Texas," *Amer. Jour. Sci.* (1927), pp. 381-401.

52. E. H. Sellards, H. P. Bybee and H. A. Hemphill, "Producing Horizons in the Big Lake Oil Field, Reagan County, Texas," *Texas Univ. Bull. 3001* (1930), pp. 149-203.

53. R. Staub, *Der Bewegungsmechanismus der Erde* (1928).

54. C. W. Tomlinson, "The Pennsylvanian System in the Ardmore Basin," *Oklahoma Geol. Survey Bull. 46* (1929).

55. J. A. Udden, "Notes on the Geology of the Glass Mountains," *Texas Univ. Bull. 1753* (1917).

56.———, "The Geology of the Shafter Silvermine District, Presidio County, Texas," *Texas Univ. Bull. 24* (1904).

57. J. A. Udden, C. L. Baker, and E. Böse, "Review of the Geology of Texas," *Texas Univ. Bull. 44* (1916).

58. E. O. Ulrich, "Fossiliferous Boulders and the Ouachita Caney Shale Containing Them," *Oklahoma Geol. Survey Bull. 45* (1927).

59. W. A. J. M. van Waterschoot van der Gracht, "The Deeper Geology of the Netherlands and Adjacent Regions," *Geol. Service Netherlands* (The Hague, 1909).

60. W. A. Ver Wiebe, "Ancestral Rocky Mountains," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 14, No. 6 (June, 1930), pp. 765-88.

61. Luther H. White, "Subsurface Distribution and Correlation of the Pre-Chattanooga (Wilcox sand) Series of Northeastern Oklahoma," *Oklahoma Geol. Survey Bull. 40 B* (1926).

62. Robin Willis, "Preliminary Correlation of the Texas and New Mexico Permian," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 8 (August, 1929), pp. 997-1032.

PRE-CARBONIFEROUS STRATIGRAPHY OF MARATHON UPLIFT, WEST TEXAS[1]

PHILIP B. KING[2]
Washington, D. C.

ABSTRACT

Beneath the Carboniferous strata in the Marathon uplift are rocks of Cambrian, Ordovician, and probably Devonian ages, whose total exposed thickness is 2,500 feet. Of these, the most completely represented is the Ordovician, which includes representatives of the Beekmantown, Black River (?), Trenton, and Cincinnatian of the standard sections, with a possible partial representation of the Chazy. The system is divided into five formations, four of which are new. The Cambrian is represented by sandy strata of which only the highest beds are exposed, and the Devonian is probably represented by cherts and novaculites. The pre-Carboniferous rocks of the district are of geosynclinal facies, with terrigenous clastic members. They have little in common, in either lithology or faunas, with the sections near by, at Van Horn, Big Lake, or the Llano-Burnet uplift. They have many resemblances to the section in the farther removed Ouachita Mountains, where the strata are also prevailingly clastic, with many siliceous beds, and with graptolites as the chief element in their faunas. This is thought to be the result of the influence of the old land mass of Llanoris.

HISTORICAL SUMMARY

The existence of pre-Carboniferous rocks in the Marathon region was first noted by Robert T. Hill,[3] who in 1900 described "closely folded, buckled. . . . Paleozoic limestone, shales, and cherts, probably of lower Helderberg age." They were later studied by Udden[4] on his journey to the Chisos country, when various fossils, including *Trinucleus* (*Cryptolithus*) were collected "along the wagon road near Ridge Spring, and at different points south from this place for a distance of ten miles"; these were correlated with the Trenton by Schuchert.

The first important stratigraphic work in the area was that of Baker and Bowman,[5] who, as a part of a 4-months' exploration in West

[1]Read before the Association at the San Antonio meeting, March 19, 1931. Manuscript received, April 14, 1931. Published by permission of the director of the United States Geological Survey.

[2]United States Geological Survey.

[3]R. T. Hill, Physical Geography of the Texas Region, *U. S. Geol. Survey Topographic Atlas Folio 3* (1900), p. 4.

[4]J. A. Udden, "Sketch of the Geology of the Chisos Country," *Texas Univ. Bull. 93* (1907), pp. 18-20.

[5]C. L. Baker and W. F. Bowman, "Geologic Exploration of the Southeastern Front Range of Trans-Pecos Texas," *Texas Univ. Bull. 1753* (1917), pp. 79-101. A preliminary statement in "Review of the Geology of Texas," *Bull. 44* (1916), contains the first description of the formations which they distinguished.

Texas in 1915, collected fossils and made brief studies of the pre-Carboniferous succession. The fossils were studied by E. O. Ulrich, who recognized six distinct faunas in the collections, and the section was divided by Baker and Bowman into four formations on the basis of the fossil determinations and the lithology. Table I shows Baker and Bowman's formations and the six corresponding faunal zones of Ulrich.

TABLE I

Formations of Baker and Bowman, 1917		*Fossil zones of Ulrich, 1917*
Caballos novaculite		
Maravillas chert		Zone VI—Fernvale horizon of the Richmond group Zone V—Middle and upper Viola limestone of Oklahoma; Trenton of New York
Marathon series	Member 5	Zone IV—Lower Viola and lower Trenton of New York
	Member 4	
	Member 3	Zone III—*Phyllograptus* zone; middle to upper Ouachita shale of Arkansas; middle Canadian
	Member 2	
	Member 1	Zone II—*Symphusurina* zone; upper Ozarkian of Mississippi valley, Chepultipec chert of southern Appalachians
Brewster formation		Zone I—Upper Cambrian; Dunderberg shale of Nevada

The discouragements offered by the complex structure of these ancient rocks, with their small-scale folding and overthrusting, and the difficulties of fossil collecting, have prevented any further contribution to knowledge of the section since Baker and Bowman's exploration.

Field work by the writer for the United States Geological Survey was begun in the region in 1929, and continued with detailed mapping and fossil collecting in 1930. The present paper is a preliminary statement of the results of these studies, issued in advance of a publication by the survey, to make some of the more significant conclusions immediately available to other geologists working in the region. The writer is deeply indebted to Charles L. Baker of the Rio Bravo Oil Company,

who has made available many recent fossil collections in the region for paleontologists of the United States Geological Survey to study, and who joined the writer in several field conferences which made possible a correlation between the present work and the original work of Baker and Bowman in 1915. Fossils collected by the writer and others have been studied by Edwin Kirk, E. O. Ulrich, and Rudolf Ruedemann, but the identifications, and opinions on correlations herein expressed, are very largely derived from field and office conferences with Edwin Kirk.

GENERAL FEATURES

The pre-Carboniferous strata of the Marathon uplift, with an exposed thickness of about 2,500 feet, are brought to the surface in the Marathon and Dagger Flat anticlinoria,[1] in the central part of the Marathon basin. The higher members of the succession also appear in anticlines of less height between the two anticlinoria, and south of them. The uplifted areas are surrounded by synclinoria of Carboniferous sandstones and shales. All the strata are intensely deformed by late Pennsylvanian orogeny, though they are only slightly metamorphosed.

Seventeen stratigraphic sections were measured during the course of the field work, of which only five extend entirely from the Cambrian through the probable Devonian. Four sections in the area, where there were good exposures and relatively simple structure, were studied with greatest care: (1) a section on the south side of the road to the Roberts Ranch 3 miles west-southwest of Old Fort Peña Colorada and 7 miles southwest of the town of Marathon; (2) a section between Woods Hollow and Little Woods Hollow, on the old Louis Granger Ranch, 6 miles southeast of Marathon; (3) a section on the south side of the Woods Hollow Mountains 3 miles northeast of Woods Hollow Tank; and (4) a section on the south side of Dagger Flat 4 miles northeast of the Buttrill Ranch.

Rocks of Upper Cambrian, Lower, Middle, and Upper Ordovician, and probably Devonian age are present, with the base of the Paleozoic not exposed. All the formations contain fossils in greater or less quantity, but collecting is nearly always difficult, as it entails the splitting of great quantities of slaty shales and thin-bedded limestones, which bear little or no surface indication of the presence of organic remains. The best fossils are obtainable in finely granular limestone, where there has been little compression of the fragile remains of the brachiopods, trilobites, and graptolites which they enclose.

[1] P. B. King, "The Geology of the Glass Mountains," Pt. 1, *Texas Univ. Bull. 3038* (1930), Fig. 34.

The Marathon section is composed of relatively thick beds of shale, muddy limestone, and chert, with intercalated layers of conglomerate, boulder beds, and sandstone. The faunas are mostly of a specialized facies, with plentiful floating and attached graptolites, associated with linguloid and oboloid brachiopods, pteropods, and trilobites. A very different contemporaneous facies is found 100 miles northwest, at Van Horn and El Paso, where the rocks are nearly all dolomitic limestones, which contain faunas characterized by orthoid brachiopods, cephalopods, gastropods, corals, and sponges. The differences between the two sections have, however, been emphasized at the expense of the resemblances, for several fossils and a few faunal groups are found in both regions, and there is no suggestion that the strata were deposited in separated seaways. It is very probable that the more or less clastic pre-Carboniferous strata at Marathon were formed on or near muddy shores, in agitated waters above the level of wave base, and that the limestones with the gastropod-cephalopod assemblages were deposited farther from shore in clean and quiet water.

These changes of facies are characteristic of the early Paleozoic rocks in a wide area in the southwest. The limestone facies, with its cephalopods, gastropods, and associated fossils, are typically developed not only near El Paso and Van Horn, but also in the Llano-Burnet uplift, the Wichita-Arbuckle mountains, and the Ozark uplift. The graptolite facies is exposed also in the Ouachita Mountains of Oklahoma and Arkansas, and is found in deep wells east and south of the Llano-Burnet uplift.[1] The differences are seemingly caused by the influence of Llanoris,[2] the old Paleozoic borderland on the southeast, which was actively rising and being stripped of sediments during the greater part of Paleozoic time. Most of the clastic materials were caught in the geosynclinal area along its northern base, where the rocks of the Marathon area and of the Ouachita Mountains accumulated.

[1]Described by E. H. Sellards and H. D. Miser in several papers now awaiting publication.

[2]The name Llanoris (Llanoria) as here used, is intended to apply to the Paleozoic land, probably composed of crystalline rocks, which lay southeast of the Marathon region. This is supposed to join the original Llanoria described by Miser (1921) somewhat after the fashion shown by the writer in *Texas Univ. Bull. 3038*, Fig. 40. Llanoris is not to be confused with the Llano-Burnet area or Central Mineral region which had a very different history. Its western end is supposed to have been connected with another land, Columbia, of which very little is known. For the present, in view of the similar physical history, and probable actual connection, the name Llanoris will be used for the hinterland of both the Ouachita and Marathon folds.

CAMBRIAN SYSTEM

Problem of "Brewster formation."—In 1915 Baker and Bowman collected fossils from two anticlinal mountains 8-12 miles south of the town of Marathon, the one locality being northeast of the Bourland Ranch 6 miles northeast of the junction of Peña Colorada and Maravillas creeks, and the other on the Combs Ranch 1½ miles northeast of the creek junction. The higher fossil collections from both places were from the Maravillas chert, but below this, fossils were found in nodular masses of dense or crystalline gray limestone, in part mottled, and in part glauconitic, imbedded in clay shales and brown sandy flagstones. The base of the lower series was not exposed. In collections from both localities Ulrich distinguished an Upper Cambrian fauna "like..... that found in the Dunderberg shale of the Nevada....section"[1] and in addition, at the second place, a fauna characterized by *Symphusurina*, to be correlated with "a well-marked zone in the lower part of the Pogonip of Nevada...." of which "the evidence permits of only one conclusion....namely that it is Ozarkian, and most probably Upper Ozarkian" (p. 83). On the basis of these determinations, Baker and Bowman set off the lowest beds at the Combs Ranch locality as the "Brewster formation," of Upper Cambrian age, named for Brewster County. The similar clays and flagstones lying above them, containing the "Ozarkian" fossils, they considered to be member 1 of their "Marathon series." The direct superposition of Maravillas (Upper Ordovician) on supposed "Ozarkian" at this place and the absence of intervening Ordovician zones of other localities was explained by a marked erosional unconformity at the base of the upper formation.

Recent collecting at these localities has disclosed some puzzling anomalies not explained by the first interpretations. The sandy flagstones and the matrix of many thin layers of interbedded conglomerate

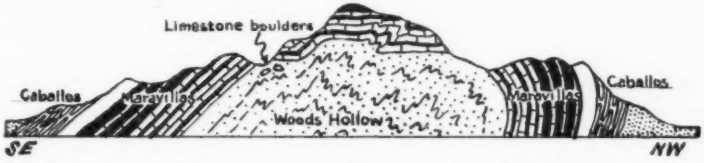


FIG. 1.—Structure section across northeast end of anticline 8 miles south-southwest of Marathon, to show structure at locality of Baker and Bowman's original Cambrian fossils. The fossils are in limestone boulders, imbedded in shaly and sandy strata with Trenton fossils. Length of section, 1 mile.

[1]Baker and Bowman, *op. cit.*, p. 81.

are profusely fossiliferous at different levels below, between, and above the limestone "nodules." The flagstone fossils are largely species of *Diplograptus* and *Climacograptus*, and the conglomerate fossils are various bryozoans, brachiopods, trilobites, and crinoids; in the surrounding region these fossils characterize the Middle Ordovician Woods Hollow shale described hereafter. Furthermore, southwest of Garden Springs the Woods Hollow shale, here plainly overlying the earlier Ordovician, also contains large "nodules" of mottled and of glauconitic limestone. Further collecting from the "nodules" of the Combs Ranch locality has, however, greatly expanded the faunas first described, and has given plentiful evidence that the fossils are actually Cambrian and early Ordovician.

It is here suggested that the "nodules" are in fact large erratic boulders of Cambrian and Ordovician limestones, imbedded in the shaly and flaggy strata of the Middle Ordovician Woods Hollow beds. It is also possible that they are of a facies foreign to the Marathon geosyncline, as their lithology is quite unlike indigenous rocks of the same age, and as their faunas have not been revealed by the most diligent collecting from ledges in place.

It is therefore clear that the type section of the "Brewster formation" is a part of the Woods Hollow shale, that the name "Brewster" should be abandoned, and that a new name should be given to the indigenous Cambrian strata. The name Dagger Flat sandstone is here proposed for these beds.

Dagger Flat sandstone.—The Dagger Flat sandstone is the oldest rock found in place in the Marathon region, and its base is nowhere exposed. It is exposed in long narrow belts in the center of the anticlines in both the Marathon and Dagger Flat anticlinoria, but the widest area of exposure is on the south side of Dagger Flat northeast of the Buttrill Ranch, where massive sandstones form conspicuous ledges. This is chosen as the type locality of the formation. There are also several extensive outcrops along the anticlinal axes northeast of Woods Hollow Tank. The rocks comprising the formation were included by Baker and Bowman[1] in their section on "Three-Mile Hill" (3¼ miles northeast of Maravillas Gap) and designated, without age assignment, as a member of their "Marathon series."

The Dagger Flat beds are in all places so intricately contorted that the exposed thickness is not exactly known; a probable maximum of 300

[1]Baker and Bowman, *op. cit.*, p. 83.

feet is found on the south side of Dagger Flat. The lowest strata here are conspicuous ledges, each 4 or 5 feet thick, of white, saccharoidal, moderately coarse-grained sandstone, weathering pale brown. In places these pass into fine conglomerate of rounded vein quartz pebbles, some of which show a notable secondary re-growth of the quartz crystals. The massive sandstones pass upward into flaggy and thinly laminated brown and greenish micaceous sandstones, with much interbedded shale, the latter predominating toward the top. In the upper part several layers of laminated calcareous brown sandstone contain the cephalons of various trilobites, including *Agnostus*, and many shells of *Lingula* and *Obolus*. There are also several layers of conglomerate composed of small black chert, gray limestone, and clear quartz pebbles in a brown sandy limestone matrix. Northeast of Woods Hollow Tank, nodular layers of sandy limestone are plentiful, which weather to a peculiar chocolate-brown velvety surface; some of the more calcareous of these contain *Agnostus* and other trilobites.

The original exposures described by Baker and Bowman on "Three-Mile Hill" show rocks similar to those on the Buttrill Ranch, but here so intensely contorted that the massive sandstones have been sliced into lenses, or rolled into boulder-like masses, around which the shales have been squeezed, and indurated nearly to slates. At this locality the Dagger Flat is overlain in places by a thin layer of what is here called Marathon limestone, followed by little deformed Woods Hollow shales and earthy limestones, and by Maravillas chert. Similar intense contortion is found at Maravillas Gap, where the Dagger Flat sandstones are overlain, locally with a marked difference in dip, by the Maravillas chert. The writer considers these relations to be tectonic rather than stratigraphic, and believes that the trace of an overthrust extends along the northwest base of the hills in which the exposures lie. Several large areas of overthrust rocks, 2 miles northwest of Three-Mile Hill, now isolated from their roots by erosion, are probably the northern extensions of the upper strata of Three-Mile Hill.

The fossils of the Dagger Flat sandstone are poorly preserved and difficult to collect. The largest collections, made in the Dagger Flat anticlinorium, are nearly all characterized by *Agnostus*, *Lingula*, and *Obolus*. They have been studied briefly by Edwin Kirk and C. E. Resser, who consider the material to be Upper Cambrian in age. The top of the Dagger Flat sandstone lies immediately beneath the lowest occurrence of *Dictyonema* and other dendroid graptolites, which range down to the base of the succeeding Marathon limestone.

ORDOVICIAN SYSTEM

The Ordovician system, as exposed in the Marathon basin, includes five formations. In ascending order, these are the Marathon limestone, Alsate shale, Fort Peña formation, Woods Hollow shale, and Maravillas chert. The first and fourth of these formations, though newly defined, were described by Baker and Bowman as a part of their "Marathon series" in 1917, together with what is here called the Dagger Flat sandstone. The second and third formations were not seen by them and are described here for the first time.

The "Marathon series" was named for the Marathon region, without reference to definite type locality, and consisted of five members, in which three faunal zones, of "Ozarkian," "Canadian," and lower Trenton age, were recognized by Ulrich. Table II shows the Ordovician system as now classified in the Marathon basin, and the relations of the "Marathon series" to it.

TABLE II

ORDOVICIAN SYSTEM IN MARATHON BASIN, TEXAS

System	*Baker and Bowman, 1917*		*Ulrich's Zones, 1917*	*King, 1931*
	Maravillas chert		Zones V and VI	Maravillas chert
	Marathon series	Member 5 Member 4 Member 1 and Brewster formation	Zone IV Zones I and II (in boulders)	Woods Hollow shale
Ordovician		Not seen		Fort Peña formation
		Not seen		Alsate shale
		Member 3 is a small part of Marathon limestone	Zone III	Marathon limestone, including: c) upper member b) Monument Spring dolomite member a) lower member
Cambrian		Member 2		Dagger Flat sandstone

Marathon limestone.—Table II demonstrates that the term "Marathon series," as used by Baker and Bowman, is too inclusive and indefinite for further use, and it is here proposed to restrict the term to the lime-

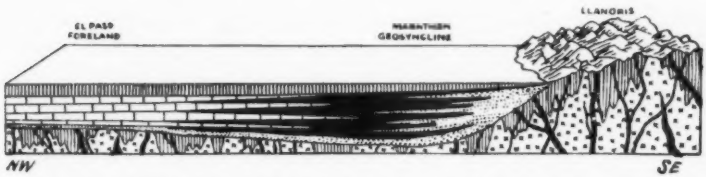


FIG. 2.—Hypothetical section showing probable paleogeography in region of Marathon geosyncline in Ordovician time. Length of section, several hundred miles.

stones and associated rocks which actually crop out within the town of Marathon. These strata, which are a well-marked unit of Deepkill (Beekmantown) age, are exposed in the streets and vacant lots of the town. The basal beds, resting on Dagger Flat sandstone, crop out a mile southwest of the railway station on the north side of the old road to Alpine, and the highest layers, dipping beneath the Alsate shale, occupy a northeasterly belt of outcrop which crosses the Boquillas road 1¼ miles south of the station.

Other good exposures are on the south side of the road to the Roberts Ranch, 3 miles west-southwest of Old Fort Peña Colorada, with part of the formation beautifully revealed ½ mile northeast in the bed of Alsate Creek, on the opposite side of the road. There are extensive exposures of the formation in the northeast end of the Dagger Flat anticlinorium, northeast of Woods Hollow Tank.

The Marathon limestone ranges between 500 and 1,000 feet in thickness in the Marathon anticlinorium and most of the Dagger Flat anticlinorium, but thins to only 350 feet in the southernmost exposures. The section most carefully measured, 3 miles west-southwest of Fort Peña Colorada, is 800 feet thick. The most conspicuous parts of the formation are beds of flaggy, dense, gray or black limestone, weathering ashen gray or bluish, and breaking with conchoidal fracture; with partings of shale separating most of the layers. Some of the dense limestones contain granular seams or lenses spotted with bituminous matter, which form mats of tangled graptolite stipes and crushed linguloid and pteropod shells. There are a few thin layers of globular silicified sponges, and the weathered surfaces of some of the beds are thickly strewn with separated spicules of hexactinellids. Some of the dense limestones are traversed by vertical cylindrical tubules filled by calcite, probably the traces of algae; and some are penetrated by small tubes and pockets of comminuted organic material, perhaps the excrement of some burrowing animal.

The limestone bedding surfaces show channel markings, small pockets filled by cross-bedded sand, and here and there, in the more argillaceous parts, well-developed mud cracks.

Besides the many shale partings there are a few thick members of greenish clay shale and the argillaceous parts of the formation, though in few places well exposed, probably comprise ⅓ or ½ the total thickness. Between the limestones are a few layers of sandstone, and many 1-foot to 4-foot beds of intraformational conglomerate, composed of shattered limestone flags, turned this way and that and cemented by granular limestone. Some of the limestone layers also contain more distantly derived, well-rounded pebbles of chert, limestone, and vein quartz. In the southern part of the area are some thin members of bedded black and brown chert.

Near the middle of the formation is the Monument Spring dolomite member, typically exposed ½ mile west of Monument Spring. The member reaches 75 feet in thickness in the Marathon anticlinorium, where it has a wide and persistent development, but it thins southeastward to a few feet in the northern part of the Dagger Flat anticlinorium, and disappears beyond that. The member is a dense massive dolomitic limestone, mottled yellow and bluish, and on weathered surfaces changes to a spongy brown chert. According to Edwin Kirk it has a strong lithologic resemblance to the lower half of the El Paso limestone at El Paso. As a result of deformation, the competent Monument Spring dolomites have been broken and shattered, so that the outcrop is characteristically a chain of disconnected boulders. By deformation also, the layer has been repeated in a most bewildering manner, and only careful field mapping does away with the impression that there are many of these beds in the section instead of one. The interbedded limestone flags above and below the Monument Spring dolomite member are identical in aspect, and are not distinguishable in the field.

The faunas of the upper and lower members of the Marathon limestone are similar in character, though they represent distinct zones in the Deepkill section. The most common graptolite genera are *Tetragraptus*, *Phyllograptus*, and *Didymograptus*, but at some localities *Goniograptus* and *Loganograptus* are also found. Various dendroid graptolites, including *Dictyonema*, are found throughout both the lower and upper members. Associated with the graptolites are many linguloids and oboloids, a few pteropods and trilobites, and in some zones many sponges. As these faunas are to be correlated with part at least of graptolite beds 1 to 5 of the section at Deepkill, they belong to the Beekmantown.

The fauna of the Monument Spring dolomite is of a distinct facies. It contains plentiful masses of *Cryptozoön*, at least three species of sponges, which include *Calathium* cf. *formosum*, undetermined orthoid brachiopods, and various poorly preserved gastropods. A single cystoid calyx was found, but stem segments occur in the rock in great numbers. Cephalopods are plentiful and well preserved, the most characteristic being *Piloceras*, and the endoceratoid *Colpoceras*. According to Kirk this fauna is nearly identical with that in the lower half of the El Paso limestone at El Paso, but particularly in the beds several hundred feet above its base.

Alsate shale.—The Alsate shale is named for Alsate Creek,[1] which joins Peña Colorada Creek from the west at Fort Peña Colorada. The shale is well exposed in a cut on the creek 2½ miles west-southwest of Fort Peña, near the road to the Roberts Ranch, and it is widely distributed in narrow, convoluted belts of outcrop in both the Marathon and Dagger Flat anticlinoria. In most places the shale occupies a soil-covered interval between the ledges of the Marathon and Fort Peña limestones.

The Alsate shale is a thin but distinctive formation overlying the normal Deepkill horizons in the Marathon formation, set off both above and below by conglomerates, and characterized by the exotic graptolite *Oncograptus*. The formation consists of two facies: in the northern exposures it is mostly shale, but in the south there are many limestone ledges. Southeast of Marathon the limestones come beneath the shale beds, but as the faunas show no great difference in age, the two facies probably intergrade.

Near the type locality the formation consists of 25-50 feet of indurated greenish shale, in part siliceous, containing nodular beds of dense yellow-weathering limestone, and lenses of saccharoidal buff quartz sandstone, passing locally into fine conglomerate. In places the shales contain spherules of radiating marcasite crystals. At the base is a coarse conglomerate layer of irregular thickness, composed of rounded limestone and chert fragments.

In the Dagger Flat anticlinorium, where the formation is 125 feet in thickness, limestone ledges are conspicuous, but each is separated from the next by 3-5 feet of poorly exposed shale. The limestones are

[1]Named for Alsate, chief of the Chisos Apaches, who once occupied this territory. Fort Peña Colorada, near by, was established in the seventies to check the depredations of his and other marauding bands. Kokernot Spring, near Alpine, was once called Charco de Alsate.

similar to those in the overlying Fort Peña formation, and are gray-brown, sandy, finely granular, and laminated, with bands of brown silica on weathered surfaces. There are also some thin beds of dense limestone, weathering yellow or buff, and in part laminated by fine dark bands.

The limestones of the Alsate formation in the Dagger Flat anticlinorium contain graptolites in thin zones, nearly everywhere including the remarkable genus *Oncograptus*, hitherto known only in Australia, British Colombia, and Idaho. Ruedemann[1] interprets the genus as an aberrant offshoot of *Didymograptus* in the Pacific realm at a horizon probably corresponding with graptolite beds 3 to 7 of the Deepkill section. Associated with this genus are several species of *Didymograptus*, including one with extremely large stipes; also *Tetragraptus* and different dendroids. In the Alsate Creek area fossils found in some of the limestone nodules include *Tetragraptus*, *Phyllograptus*, and *Didymograptus*, a small species of *Orthis*, a small *Seleneceme* and other trilobites, and a *Maclurea* seemingly identical with a new species collected by Edwin Kirk high in the Beekmantown horizon of the Pogonip limestone of Nevada.

The Alsate graptolites are of high Deepkill age, and the *Maclurea* indicates that the formation is also to be correlated with some part of the highest Beekmantown.

Fort Peña formation.—The Fort Peña formation, as the chief ridge maker in the Marathon succession below the novaculite, rises in low hogbacks out of the generally level country of the Marathon and Dagger Flat anticlinoria. The type locality is on one of these ridges directly north of old Fort Peña Colorada. Superficially, the formation somewhat resembles the Dimple formation in the Carboniferous, for which, in some places, it has been mistaken.

The formation ranges from 125 to 200 feet in thickness, and consists mostly of alternations of thick-bedded limestone and bedded chert. The limestones are coarsely granular, and in part sandy and pebbly, and crop out in conspicuous ledges several feet in thickness. There are some thin partings of shale. In the middle and upper parts are considerable thicknesses of granular, purplish, reddish, and bluish chert, mostly in thin beds. In the south part of the area, as in the region of Garden Springs, the upper part of the formation is marked by a very massive chert member in beds 3 or 4 feet thick.

At the base of the formation are 5 or 10 feet of coarse, massive conglomerate, composed of sub-rounded pebbles of chert, limestone, and

[1]Rudolf Ruedemann, "Fossil Evidence of the Existence of a Pacific Ocean in Early Ordovician Time" (abstract), *Bull. Geol. Soc. Amer.*, Vol. 39 (1928), pp. 299-300.

sandstone ranging from ¼ inch to 6 inches in diameter, which rest on the Alsate shale. The upper limestones grade into the Woods Hollow shale by a change to thinner bedding and by a thickening of the shale partings.

Fossils are uncommon except in a few thin seams in the limestones. From beds beneath the upper chert member near Garden Springs were collected *Diplograptus*, *Ceraurus*, *Bucania*, and a rafenesquinoid probably allied to *Ptychoglyptus*. Southwest of Marathon, *Climacograptus* and *Diplograptus* are plentiful, and in places beautifully preserved. Associated with them are oboloid and linguloid brachiopods, and a small *Orthis* of the type *O. tricenaria*. In several of the collections southwest of Marathon there are also large stipes, seemingly of *Didymograptus*, and specimens of a recurved *Tetragraptus*.

Most of this fauna is suggestive of the Black River, but the occurrence here and there of the two primitive genera last named, reminiscent of the fossils collected at Ashhill quarry at Mount Moreno,[1] New York, suggests that the formation is older, possibly Chazyan. The field relations of the Fort Peña suggest Middle, rather than Lower Ordovician, as its massive sandy limestones rest with coarse basal conglomerate on dissimilar Lower Ordovician strata, and as its limestones seem to grade upward into the Woods Hollow shale.

Woods Hollow shale.—The Woods Hollow shale is best exposed in the Woods Hollow Mountains, between Woods Hollow and Little Woods Hollow, in an anticlinal valley on the former Louis Granger Ranch. The formation characteristically occupies a valley between the Fort Peña hogbacks and the higher ridges of Maravillas and Caballos. In most places it is covered by soil, and crops out only in gullies and creek banks. At nearly all places its incompetent beds are intensely contorted. The Woods Hollow shale is the same as Baker and Bowman's members 4 and 5 of the "Marathon series" and the strata mentioned by them at Garden Springs, Horse Mountain, and Fort Peña Colorada. The differences noted at these localities have been overemphasized, and are at most the local facies of a single stratigraphic unit.

At the type locality the Woods Hollow beds, 470 feet thick, are beautifully revealed in an anticlinal basin, dipping in regular order off the highest Fort Peña limestones, which appear in the center. The lower part of the Woods Hollow, consisting of flaggy, thinly laminated gray or yellowish sandy limestone or limy sandstone, with some shale partings, grades upward into greenish clay shale with a few interbedded

[1]Rudolf Ruedemann, "Graptolites of New York," Part 1, *New York State Mus. Mem.* 7 (1904), pp. 499-500.

flaggy limestone layers. Some of the sandy beds are rill-marked on bedding surfaces, and some of the lower flaggy layers contain graptolites. There are five or six nodular beds of coarsely granular and conglomeratic limestone, weathering yellowish, crowded with the comminuted remains of bryozoans, trilobites, brachiopods, and crinoids.

Other exposures are similar. A few miles southeast of Marathon, and also near Peña Blanca Spring, a 30-foot member of flaggy quartzitic sandstone is locally prominent. The shales, sandy and limy flagstones, and conglomeratic limestones which lie beneath the Maravillas in the anticlines on the Combs and Bourland ranches are of Woods Hollow age, but at these places, as well as near Garden Springs, they contain large rounded masses of hard gray limestone, in part mottled, and in part glauconitic. From these, Cambrian and early Ordovician fossils have been collected both by Baker and the writer, showing beyond question that they are boulders imbedded in much younger strata. As previously explained, the lower part of the Combs Ranch exposure was named the "Brewster formation" by Baker and Bowman, and considered Upper Cambrian, but this interpretation is now discarded.

Fossils are plentiful in the Woods Hollow shale, but are nearly all comminuted and poorly preserved. *Diplograptus* is common in the lower flags at the type locality. Higher, in the more crystalline limestones are ramose and massive bryozoans, including *Phaenopora*, *Nicholsonella*, *Rhinidictya*, and *Anolotichia;* the trilobites *Illaenus* and *Asaphus;* the molluscs *Modiolopsis* and *Holopea;* and *Orthis* near *O. tricenaria*. Along the road between Ridge Spring and Garden Spring were collected *Dicellograptus*, *Diplograptus*, *Glossograptus*, *Ceraurus*, and a large *Hormotoma*. The other collections, including that made southwest of the Lochausen Ranch by Böse,[1] are so similar that they need not be detailed here. The Woods Hollow shale is Middle Ordovician, of approximately Trenton age, though it may extend as low as the Black River.

Maravillas chert.—The Maravillas chert was named by Baker and Bowman for exposures at Maravillas Gap, 20 miles south of Marathon in the Santiago Peak Quadrangle. Excellent exposures are also found on the northwest slope of "Three-Mile Hill," 3¼ miles northeast, and at Fort Peña Colorada, east of the picnic grounds in the gap. As originally described, it was said by Baker and Bowman[2] to reach 800 feet in thickness, and to contain rocks of both Trenton and Richmond ages.

[1]Baker and Bowman, *op. cit.*, p. 85.

[2]*Op. cit.*, pp. 89-92.

However, on a re-examination of the exposures in company with Baker, it was concluded that the original measurements were not corrected for local duplication, and Edwin Kirk believes, after a new study of the faunas, that the formation is entirely of Upper Ordovician age. The name Maravillas is here applied, with different interpretation, to the same strata for which it was used by Baker and Bowman.

The Maravillas chert ranges from 100 to 200 feet in thickness in the Marathon anticlinorium, but it thickens southward to 400 feet. It consists of interbedded limestone and black, bedded chert, the latter predominating toward the top, which crops out on the inner slopes of the novaculite cuestas.

The lower, limestone part of the formation is sharply set off in places from the upper cherty part. Near Marathon it consists of somewhat thick ledges of finely granular dark gray limestone, with thin interbedded layers of brown and gray chert, and of thin-bedded dense bituminous limestone, giving a fetid odor when struck. Graptolites are very plentiful on the bedding surfaces of the denser limestones, and the granular limestones contain brachiopods and trilobites. In the south part of the area, in the upper part of the limestone member, are reef-like aggregates of bryozoans, some of which form massive beds with a maximum thickness of 10 feet. In most exposures near Marathon there are, in the lower member, three or four conglomerate beds, as much as 4 feet in thickness, of limestone and chert pebbles in a granular calcareous matrix. Most of these contain cup and colonial corals, and brachiopods, bearing marks of attrition, but of approximately the same age as the fossils in the associated beds. Southwest from Marathon toward the Roberts Ranch, the lower limestone ledges are replaced by conglomerate, which forms massive ledges 10 or 20 feet thick near Monument Spring and Rock House Gap.[1] At both these places the lower conglomerates contain cobbles and boulders, with a maximum thickness of 7 feet, of earlier rocks, including Woods Hollow flagstones, Fort Peña chert, Monument Spring dolomite, and particularly sandstones in part identical with those in the Dagger Flat formation. These lie in a matrix of granular sandy limestone crowded by small pebbles and grits of black chert. Rolled colonial and cup corals are plentiful in the finer conglomerate beds. In the upper part they are interbedded with thin layers and lenses of black chert.

The upper part of the Maravillas formation consists of little else than black, dull-lustered, bedded chert, mostly in thin beds, but with

[1]According to C. L. Baker, this locality is the same as the "Payne Ranch" locality mentioned by him and Bowman in *Bull. 1753*, on p. 91.

some massive layers 3 or 4 feet thick which are aggregates of pillow-like nodules. The chert breaks into small blocks on weathered surfaces, similar to lumps of coal. There are a few thin interbedded layers of bituminous limestone, and between many of the chert layers are shale partings. About two-thirds of the way up in the formation is a persistent shaly layer 5 feet thick which makes a small slope on the hillsides that can be followed for long distances with the eye. Most of its shale is siliceous and buff, but in places there is soft ashen clay which contains beautifully preserved graptolites.

Fossils are plentiful at many levels in the Maravillas formation, but particularly in the lower limestone beds. A few graptolites were obtained in interbedded limestones of the chert series, and in some of the shale partings within a few feet of the top of the formation.

The conglomerates at and near the base of the Maravillas contain many rolled fossils, which include *Columnaria*, *Halysites*, *Paleofavosites*, and *Streptelasma* among the corals, and *Platystrophia* and *Hebertella* among the brachiopods. According to Kirk this fauna is like that in the basal part of the Montoya limestone at El Paso and is of nearly the same age as that in the overlying and interbedded limestones. The limestones between the conglomerates and overlying them contain *Cryptolithus*, *Harpes*, *Strophomena*, and various graptolites, including *Dicellograptus nicholsoni*, *Climacograptus antiquus*, and *Diplograptus amplexicaulis*.[1] According to Kirk, the first-named trilobite occurs in Nevada overlying a coral fauna like that in the basal Maravillas, and is also found in the Viola limestone of Oklahoma. The middle part of the Maravillas in the southern part of the basin contains lenticular bryozoan reefs, built of such genera as *Constellaria* and *Pachydictya*, in which are imbedded a few shells of *Platystrophia*, *Rafenesquina*, and *Hebertella*.[2] Kirk also has collected the genus *Cryptolithus* in the reef beds on "Three-Mile Hill." The higher beds of the formation contain little else than undetermined species of *Climacograptus* and *Diplograptus*.

The Maravillas faunas, when studied by Ulrich in 1916, were divided as those of many other western formations (Montoya limestone, Bighorn dolomite, et cetera) into a lower group, correlated with the Trenton, and an upper correlated with the Richmond. The corals and bryozoans from each locality were considered to be the younger fauna,

[1]For more extended lists see Baker and Bowman, *op. cit.*, pp. 91-92, especially the Payne Ranch locality.

[2]For further details see the extended list in Baker and Bowman, *op. cit.*, pp. 89-90, locality at Maravillas Gap.

and the trilobite *Cryptolithus* with its associated diplograptids were called Trenton. Further field work has shown that the coral fauna is interbedded with, and in many places beneath, the *Cryptolithus* fauna, and that the *Cryptolithus* fauna in turn ranges up and mingles with the bryozoan fauna. It is therefore clear that the formation is a faunal as well as a lithologic unit.

Kirk has stated his views on the Trenton-Richmond problem in the west, in a discussion of the problematical lower Bighorn.

> It has been variously correlated with the. . . . Trenton and Richmondian. Equivalent beds in Manitoba and the far north have been correlated by Foerste . . . . with the Richmond. Several years ago. . . . I suggested that this horizon was probably of Cincinnatian age [used in the sense of being pre-Richmond and post-Trenton], and. . . . a considerable amount of corroborative evidence has since come to hand. One of the most striking pieces of evidence has been the finding of *Cryptolithus* sp. in abundance in the Eureka district, Nevada, and the Marathon Basin, Texas. In the Marathon Basin. . . . [the *Cryptolithus* zone] occurs in a series of limestone carrying a fauna of post-lower Bighorn age. . . . Foerste's objections to the assignment of. . . . [the lower Bighorn horizon] to the Trenton appear valid to me. I do not see the necessity of skipping the lower Cincinnatian, however, as he does, and correlating with the Richmond.[1]

Kirk therefore believes that the Maravillas is Upper Ordovician, probably to be correlated with a part of the Montoya limestone of the El Paso section. There is a strong lithologic resemblance between the cherts and limestones of the Maravillas and the cherty limestone of the Montoya, but the latter lacks thick members of bedded chert in which limestone is absent. Like the Montoya, the Maravillas consists of heavy-bedded, sparingly cherty limestones in the lower half, and of very cherty beds above.

Maravillas-Caballos interval.—The contact between the Maravillas and Caballos formations was carefully studied at many places. At one or two of these it is marked by conglomerate, but at most of them the vitreous brown, buff, or gray chert of the lower chert member of the Caballos overlies with sharp contrast the dull coal-black nodular cherts of the Maravillas. Some evidence for post-Maravillas erosion is afforded by the irregular thickness of beds between the base of the Caballos and the "shale zone" of the Maravillas, a circumstance which is further emphasized by the constancy in thickness of members below the "shale zone."

[1] Edwin Kirk, "Harding Sandstone of Colorado," *Amer. Jour. Sci.*, 5th Ser., Vol. 20 (1930), pp. 464-65.

In 1917, Baker and Bowman noted "a small amount of light brown arenaceous shale, weathering pinkish," at a locality 8 miles northeast of the junction of Peña Colorada and Maravillas creeks.[1] Shale of this description, about 5 feet thick, was seen by C. L. Baker and the writer at one place near Maravillas Gap. At the crest of the anticline on lower Rough Creek, and at several other places southeast and south of Horse Mountain, the writer has seen thin layers of green slaty shales between the two formations.

These shales may be simply an argillaceous phase of either the Maravillas or Caballos cherts. Josiah Bridge has collected graptolites from similar pinkish siliceous shales at the top of the Maravillas chert at Fort Peña Colorada, proving their Ordovician age at this place. Baker and Sellards, however, have recently discovered a well-marked shale unit between the Maravillas and Caballos formations in the Solitario uplift, southwest of the Marathon region, and it may be that some of these shales represent the remnant of deposits laid down in the post-Maravillas pre-Caballos time interval. If the latter is true, it is possible that formerly they had a wider extent, and have since been removed by pre-Caballos erosion, or by tectonic squeezing.

DEVONIAN (?) SYSTEM

Caballos novaculite.—The Caballos formation was named by Baker and Bowman for exposures on Horse (Caballos) Mountain, the highest summit in the folded beds in the Marathon basin. The resistant white novaculites of the formation are the chief ridge makers in the area. The structure of their outcrops, convoluted by folds, duplicated repeatedly by overthrust and imbricate faults, and slashed by transverse flaws, is all beautifully revealed in the desert environment of sharp ridges and sparse vegetation.

The Caballos formation has a maximum measured thickness of 600 feet in the south part of the area, and is only 200 feet thick in the extreme northwest part. The novaculite, although predominant in the southeast, gives place northwesterly to bedded chert, which at the farthest exposures in that direction has many shale partings and a few limestone intercalations. In the north, a lower novaculite member is very prominent, but is subordinated to an upper novaculite which wedges in southward. The chert and novaculite beds are divisible into five members, from below upward: (1) lower chert member; (2)lower novaculite mem-

[1]Baker and Bowman, *op. cit.*, p. 89. Baker, in a letter to Ulrich, October 23, 1916, gives the shale locality as Maravillas Gap, the place where it was actually seen by the writer later.

ber; (3) middle chert member; (4) upper novaculite member; (5) upper chert member. The members change in thickness from northwest to southeast across the area, so that various facies of the formation can be distinguished along northeast-trending belts. The stratigraphy and facies of the Caballos formation are summarized in Table III.

TABLE III

FACIES CHANGES IN CABALLOS NOVACULITE

	Locality	*Character*	*Average Thicknesses (Feet)*				
			Lower Chert	*Lower Novaculite*	*Middle Chert*	*Upper Novaculite*	*Upper Chert*
I	Dugout Creek area	Nearly all bedded chert; many shale partings, and some limestone lenses	10	15	.....	125	.....
II	Marathon anticlinorium (southeast flank): Monument Spring, Fort Peña	Lower novaculite prominent, succeeded by a thick member of bedded chert	15	115	"Santiago chert" of *Bull. 44*, 1916 125	5	150
III	Dagger Flat anticlinorium (northwest flank): Warwick to Ridge Spring	Lower novaculite prominent; upper novaculite thin but prominent	20	60	135	25	100
IV	Dagger Flat anticlinorium (southeast flank): Lochausen Ranch, Horse Mountain, and Three-Mile Hill	Upper novaculite very prominent, lower novaculite subordinate	Caballos novaculite of *Bull. 44*, 1916 15	15	80	150	125
V	Ridges southeast of Dagger Flat anticlinorium	Like facies IV, except that the upper chert member is changing to novaculite. The lower three members are thin and insignificant					

The marked changes in facies have, unfortunately, led to some confusion in the stratigraphy. In the preliminary announcement of Baker and Bowman's work, in 1916,[1] the Caballos, with limits not clearly defined, was said to be followed by the "Santiago chert," ranging from 20 to 450 feet in thickness, which they later state was named "from a

[1] *Bull. 44*, 1st ed. (1916).

locality at the east base of the Santiago Range, east of the range's summit" (p. 100). The formation was rejected in 1917 because

> later work by the senior author seems to indicate that they are really one formation, two members of both the original Caballos and "Santiago" being included in the section at some localities (p. 94).

The original "Santiago" is said to be the same as the "lower chert member" of 1917 (middle chert member of this paper). The writer's work has afforded complete confirmation of the later interpretation, except that the absence of an upper novaculite in facies I and II is shown by a tracing-out of beds to be the result of a thinning of the member, rather than of pre-Tesnus erosion. It seems that the type Caballos of 1916 (on Horse Mountain) comprised the lower chert member, the lower novaculite member, the middle chert member, and the upper novaculite member. On the contrary, the type "Santiago" of 1916 (northern Marathon basin), consisted of the middle and upper chert members combined, with the upper novaculite member nearly absent between them. Because of the overlapping of the typical sections, and the stratigraphic unity of the whole series, the writer supports Baker and Bowman's decision to abandon the name "Santiago."

Thin limestone lenses between the chert beds are found at several places in the northwest part of the Marathon basin. At an exposure 1 mile west of Robert's Ranch, one of these layers contained plentiful linguloid shells. These indistinctive brachiopods are unfortunately so long-ranging that the collections probably afford no clue to the age. Baker and Bowman describe numerous radiolaria in parts of the formation.

The Caballos novaculite is so strikingly like the Arkansas novaculite of Oklahoma and Arkansas, not only in lithology but also in members, stratigraphic behavior, and thickness, that there is a strong presumption that the two are of the same age. The Arkansas has yielded fossils of Middle and Upper Devonian age.[1] Some years ago the writer and his brother suggested[2] that the northern feather edge of the Caballos passed between the Silurian (Fusselman) dolomites and the shale of Percha facies in the Franklin and Hueco mountains, but so far no work has been done to prove or disprove the supposition. Until further evidence is obtained, the United States Geological Survey classifies the Caballos novaculite as Devonian (?).

[1] H. D. Miser and A. H. Purdue, "Geology of the DeQueen and Caddo Gap Quadrangles, Arkansas," *U. S. Geol. Survey Bull. 808* (1929), pp. 58-59.

[2] P. B. King and R. E. King, "Stratigraphy of Carboniferous and Permian Rocks of Trans-Pecos Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 8 (August, 1929), p. 912.

CORRELATIONS AND GEOLOGIC HISTORY

The 2,600 feet of exposed pre-Carboniferous rocks of the Marathon uplift are Upper Cambrian, Lower, Middle, and Upper Ordovician, and Devonian (?) in age. In the Ordovician system are strata representing Beekmantown (Deepkill), Black River (?), Trenton, and Cincinnatian. It is also suggested that the Fort Peña may be as old as the beds at Mount Moreno, New York, which Ruedemann considers to be Chazy. Field evidence seems to show, however, that there is a considerable hiatus in the system between the Fort Peña and Alsate, so that the Fort Peña is tentatively regarded as Middle Ordovician. Further collecting at this horizon is desirable.

In addition to this probable hiatus, there is evidence of marked uplift and diastrophism in the region near the Middle and Upper Ordovician boundary. There are no observable overlaps, discordances, or channeled contacts, but the Middle Ordovician flagstones, in which are imbedded Cambrian and Ordovician exotic blocks, are succeeded above by Upper Ordovician conglomerates, which are peculiar aggregates of boulders, cobbles, and rolled fossils with indication of erosion of strata as old as the Cambrian. It should be observed that the boulder beds in both the Woods Hollow and Maravillas formations all lie in a triangle between Garden Spring, Del Norte Gap, and Monument Spring, implying a southwestward source, perhaps from an uplift a short distance west of the present Del Norte Gap. This time of disturbance is comparable with the Taconic movements of eastern United States and a widespread pre-Cincinnatian unconformity studied by Kirk in the Great Basin.

The Marathon basin section is of a different facies from that of nearby areas, but there is sufficient evidence to indicate general correlations. The Dagger Flat sandstone is probably correlative with the Bliss sandstone in the El Paso and Van Horn areas; the Marathon limestone is correlative with the El Paso limestone, and the Maravillas chert with the Montoya limestone. The beds intervening between the Marathon and the Maravillas are not represented at Van Horn and El Paso, unless the sandstone at the base of the Montoya near Van Horn is Middle Ordovician. The Caballos is either poorly represented or absent at El Paso, but here there is a thick Silurian reef limestone which has no equivalent in the Marathon region.[1]

[1]Recent fossil collections from the Solitario uplift (southwest of Marathon) which have been made by Sellards, Baker, and others, and studied by Kirk and Ruedemann, show that equivalents of the Dagger Flat, Marathon, and Woods Hollow formations are present there. The Maravillas and Caballos are also found in the Solitario in their characteristic facies.

ECONOMIC NOTES

The early Paleozoic rocks of the Marathon region contain many bituminous layers; they are particularly well marked in the Marathon and Maravillas limestones, of Ordovician age, some of which are so impregnated with bitumen that they emit a strong fetid odor when struck. There are, however, few rocks in the section at Marathon which would be good reservoir beds for oil. The Dagger Flat sandstones are too deep in the section and too well indurated to present any possibilities. The predominant shales and muddy limestones of the succeeding Marathon formation are unpromising. In the Alsate beds, which change northwesterly from limestone to shale, there are lenses of coarse quartz sand in the northwesternmost exposures. The clastics of the Fort Peña and Woods Hollow formations seem to have a southeasterly source, and the sandy beds in both of them offer some possibilities.

The observations recorded in Table IV apply only to the Marathon formations as observed on the outcrop. Considerable lateral variation is to be expected in the stratigraphy of the geosynclinal belt, because of

FIG. 3.—Hypothetical section showing possible subsurface conditions east of Marathon uplift. Three wells, *A*, *B*, and *C*, encounter very different stratigraphic and structural relations, and two of these, *A* and *B*, encounter Ordovician rocks of different facies. Well *A* is typified by deep producing wells of Big Lake oil field. Length of section, about 100 miles.

the local nature of the source of sediments. Most of the sandy layers in the section increase in prominence southeasterly toward Llanoris, but probably did not serve as oil reservoirs there, as both folding and metamorphism are more acute in this direction.

Northwest of the geosynclinal area is the prevailingly calcareous foreland facies of the Ordovician, well developed in the Llano-Burnet and El Paso areas. The Ordovician oil produced at Big Lake, Texas, is evidently from this facies. It is quite possible that the present boundary between the foreland and geosynclinal facies is along a line of overthrusting, as it is in Oklahoma along the north side of the Ouachita Mountains. A part of this fault zone may be represented at the surface by the Dugout Creek overthrust, which crops out west of the town of Marathon.

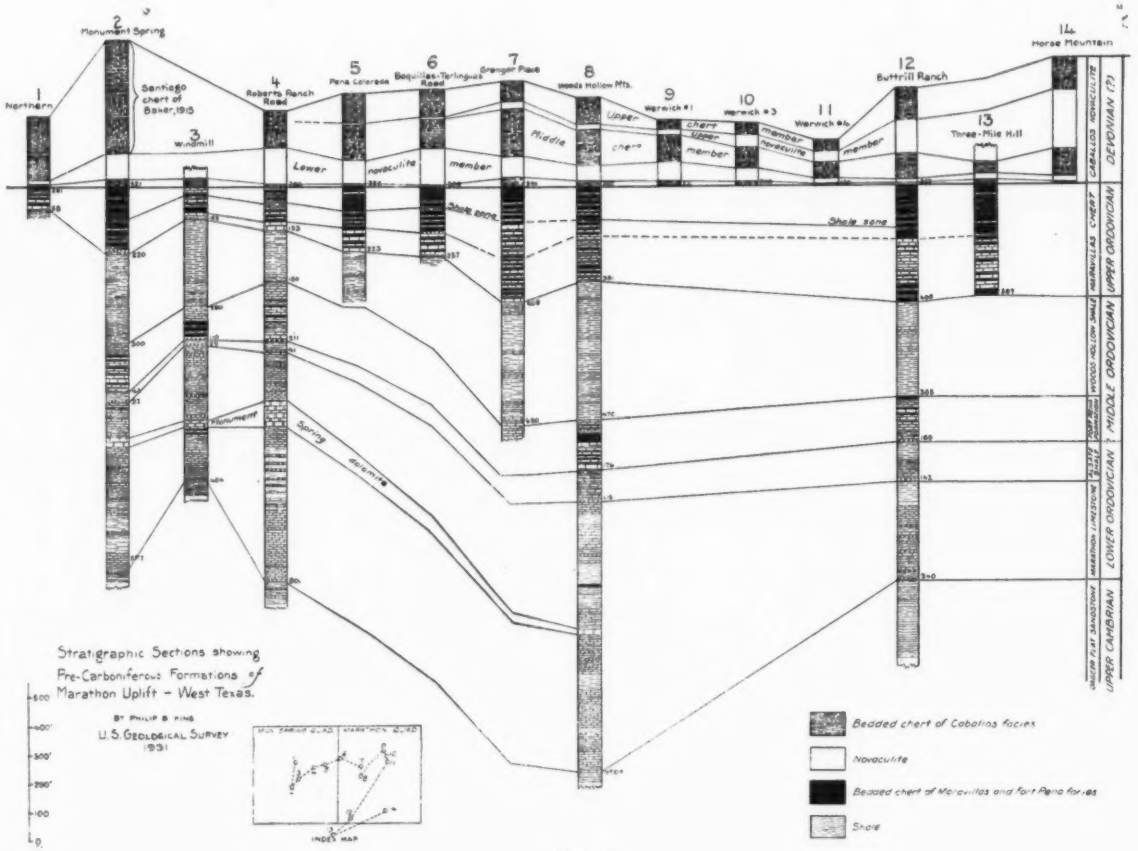

Stratigraphic Sections showing
Pre-Carboniferous Formations of
Marathon Uplift – West Texas.
By Philip B. King
U.S. Geological Survey
1931
Bedded chert of Caballos facies
Novaculite
Bedded chert of Maravillas and Fort Pena facies
Shale
INDEX MAP

FIG. 4

TABLE IV

OIL-PRODUCING POSSIBILITIES OF PRE-CARBONIFEROUS ROCKS OF MARATHON UPLIFT

Formation	*Bituminous Layers*	*Reservoir Rocks*
Caballos		
Maravillas	Most of the limestone beds are very bituminous. Some black shales	
Woods Hollow	A few beds of black shale	Many sandy intercalations in prevailing shales. The sandstones increase southeasterly
Fort Peña		Massive sandy limestones, increasingly sandy southeasterly
Alsate		Lenses of coarse sugary quartz sand interbedded in shale, which increases northwesterly
Marathon	Many bituminous limestone beds in lower and upper members	a) Sandstones in middle and upper part, increasing easterly b) Monument Spring dolomite member, possibly cavernous or porous at depth, increasing in prominence northwesterly
Dagger Flat		Sandstones which are too low in section to be promising reservoirs for oil

Abrupt changes in facies along such a structural boundary must be expected in subsurface work where the Ordovician is to be penetrated by the drill through a cover of Pennsylvanian, Permian, or Cretaceous rocks.

The eastern extension of the folded geosynclinal belt and its postulated overthrust front is not known, but there is increasing evidence to show that the system, far from ending in this direction, continues with full force beneath the Cretaceous to join the Ouachita Mountains in Oklahoma. Sellards has traced the Ouachita folds by means of drill cuttings south from Red River to San Antonio, but the scarcity of unequivocal well records between that region and Marathon makes it impossible, as yet, to locate this segment of the folded system with any exactness.

DISCUSSION

C. L. DAKE, Rolla, Missouri: I understand that Mr. Ulrich formerly correlated the Viola with the Maravillas. Recently Mr. Ulrich has expressed the view that no part of the Viola is Trenton. Do you know whether he still

correlates the two, and if so, whether he favors the idea that no part of the Maravillas is Trenton?

PHILIP B. KING: It is the conclusion of Dr. Kirk and myself that the Maravillas is Upper Ordovician in age. The Viola is commonly correlated with the Trenton. I have noticed, however, that Dr. Decker, in his recent paper on the Simpson formation, quotes Ulrich as placing the Viola as equivalent to the Eden-Maysville. If so, it might well be correlated with the Maravillas and Montoya of West Texas.

CHARLES E. DECKER, Norman, Oklahoma: It has been suggested that some of the rocks of the Marathon uplift may be equivalent to the Viola limestone of the Arbuckle Mountains of Oklahoma. Several sections of the Viola have been measured and collections of fossils made from them, but only part of these have been identified. Dr. Ulrich seems dissatisfied with the present classification of the Viola, as he expressed the wish the last time he was in Oklahoma that he might have a complete new set of fossils from the Viola for study.

H. D. MISER, Washington, D. C.: The section of rocks in the Marathon region is remarkably similar in some features to the section in the Ouachita Mountains of Arkansas and Oklahoma. The similarity suggests that the rocks of the two regions were formed in the same geosyncline. The sections in the two regions are dissimilar in many features from the sections that are exposed northwest of the geosyncline, but the Marathon rocks have more features in common with the rocks that are exposed northwest of the geosyncline than the Ouachita rocks have in common with the Arbuckle Mountain section. It thus seems that the Marathon section represents deposits that were formed somewhat nearer the inner or northwest border of the geosyncline than the Ouachita facies. In other words, the Ouachita facies seems to have been formed closer to the old Paleozoic land Llanoria than the Marathon facies. If a section similar to that in the Marathon region is present in Oklahoma, it has been concealed by the northward overthrusting of the Ouachita facies in that state.

J. A. TAFF, San Francisco, California (written discussion received, April 23, 1931): This discussion is induced by reference in Mr. King's paper suggestive of the emergence and extensive erosion of early Paleozoic strata during middle Carboniferous time in the Llano-Burnet area of Central Texas.

Exposures, particularly on the eastern and northern borders of the Llano area, show that the Devonian, the Silurian, and a considerable part of the Ordovician strata had been removed by erosion in the early Carboniferous time. The Bend shale, probably late Mississippian, rests on the eroded surface of the Ellenburger limestone between Lampasas and Llano. In the Arbuckle Mountain area in southern Oklahoma, the series or succession of early Paleozoic strata is complete from the Cambrian to the Carboniferous. The Woodford chert and Caney shale series, in part, at least, a correlative of the Bend Shale in Texas, rests on the Hunton limestone of Devonian age.

As indicated by Mr. King and remarked by Mr. Miser in his discussion, the pre-Carboniferous strata in the Arbuckle and the Wichita areas of Okla-

homa and in the Llano, Big Lake, and Van Horn areas of Texas, have common facies, particularly in their limestone and dolomite components, and suggest a connected marine province. On the contrary, the Ouachita Mountain area of southeastern Oklahoma and southwestern Arkansas, and the Marathon district of southwestern Texas, exhibit facies in common and of prevailingly clastic marine sediments of sand, shale, novaculite, and chert, with minor elements of limestone.

The research work of E. H. Sellards on deep well borings in central Texas indicates the probability that the Ouachita and Marathon areas are connected across central Texas beneath the Cretaceous, and both probably belong to a common great province of marine sedimentation. The boundary separating these provinces appears in the narrow gap between the Arbuckle-Ouachita mountains near Atoka, Oklahoma, continues thence southwestward, approximately in the Balcones fault zone, to a point a short distance east of the Llano area, and thence westerly, passing north of Marathon and south of Van Horn in western Texas.

That the Llanoria land in central Texas endured from early Carboniferous through Mississippian time and extended to the Arbuckle Mountain area in early Pennsylvanian time, is suggested by the erosion of a Devonian, Silurian, and Ordovician stratum in the Llano area, and of the same stratum in the Arbuckle Mountain area during a part, at least, of the Pennsylvanian.

The nature of the mid-Carboniferous sediments in the Ouachita Mountains in southeastern Oklahoma and southwestern Arkansas suggests extensive land areas at that time in the Texas area on the south and southwest. In this connection, reference is here made to the great number of erratic boulders in the Caney shale of the Ouachita area, identical with the limestone and dolomites of the Llano and Arbuckle facies; also, the increase in thickness and coarseness of the Carboniferous sediments, particularly of the sandstone element in the Carboniferous toward the south, suggests a land area at that time in Texas. John C. Branner, while state geologist of Arkansas, 1887-1893, in discussing the source of the great Carboniferous sandstone formations of the Ouachita Mountains in southwestern Arkansas, hypothecated an extension of Appalachian land during Carboniferous time from the southern end of the present Appalachian Mountain range in Alabama southwestward into northeastern Texas, and toward the Llano area.

PHILIP B. KING (written discussion received, May 4, 1931): Dr. Taff's valuable discussion brings out much information on the country east of that in which I have been working, and furnishes much information on the regional relations of the early Paleozoic strata.

His statements, however, bring out some different applications of terminology which should be clarified. We both refer to Llanoris (Llanoria), but he evidently makes it synonymous with the Llano-Burnet region. I used the name, however, as a convenient title for an old land mass which I suppose to have existed south of the Marathon region during Paleozoic time. In order to use it here, I have extended the term from the Ouachita region where a land mass is known to have had a similar history and position south of the Ouachita Mountains. These two old lands I think were probably connected under what is now the Gulf Coastal Plain.

Land masses, like those south of the Ouachita and Marathon folds, have had the function of hinterlands (to the folded structures) and of borderlands (to the continental margins) just as have the better known Appalachis and Cascadis.

The history of these masses has been very different from that of the Llano-Burnet area, and other regions connected with it. I believe that the two groups lay on opposite sides of the Paleozoic geosyncline and that the latter had the function of a foreland. As Dr. Taff has pointed out, the forelands are lightly mantled by a more or less interrupted sequence of Paleozoic limestones, showing that through most of the era there were no high lands here and that the history of these limestones has been a relatively passive one. I do not think that very much sediment was delivered from them into the Ouachita-Marathon geosyncline; most of that probably came from the hinterlands (Llanoris of my usage). The contrast between the two regions is further emphasized by the present structural relations. Both the Marathon and Ouachita structures are overturned away from their hinterlands toward the forelands, across which they have been partially overthrust.

In view of these important differences in history and tectonics, I think it is very unfortunate to confuse the hinterland areas with such regions as the Llano-Burnet district, the Arbuckle Mountains, and other massifs which lay on the opposite side of the geosyncline. If Dr. Taff's usage is proper, and the name Llanoris is synonymous with the Llano-Burnet district, we must search for another name for the other lands referred to. I gain the impression, however, that this name is an alteration by Dumble of the "Llano" of Willis for the very purpose of preventing a confusion of Llanoria with the Llano-Burnet region.

H. D. MISER: The hypothetical Paleozoic land area that is now known as Llanoria is a part of the extension of the Appalachians that Dr. John C. Branner in 1897 postulated as having crossed Mississippi, Louisiana, and Texas. The name Llano was applied to this old land area by Dr. Bailey Willis in 1907, but, because the Central Mineral region of Texas, frequently called the Llano region, is not a part of the old land area, Dr. E. T. Dumble introduced, in 1920, the name Llanoria for it, in order to prevent to some extent the confusion in names. The name Llanoria, or the more recent name Llanoris of Professor Schuchert, has been used by most, if not all, geologists in recent years.

Llanoria is now concealed underneath the Cretaceous and Tertiary rocks of the Gulf Coastal Plain and we know practically nothing of its rocks or history except the evidence that is revealed in regions adjacent to the Coastal Plain. The Paleozoic rocks of the Ouachita Mountains are of such character as to indicate that Llanoria was the source of sediments for the Ouachita geosyncline during Cambrian, Ordovician, Silurian, Mississippian, and Pennsylvanian time.

DETAILED CROSS SECTION FROM YATES AREA, PECOS COUNTY, TEXAS, INTO SOUTHEASTERN NEW MEXICO[1]

H. P. BYBEE,[2] E. F. BOEHMS, CARY P. BUTCHER,
H. A. HEMPHILL, and G. E. GREEN
San Angelo, Texas

ABSTRACT

Data are presented indicating that: (1) the Yates sand horizon of eastern Pecos County is correlated very definitely with the Queen sand horizon of New Mexico; (2) the anhydrite section below the base of the salt, on the eastern rim of the Central Basin platform, changes to limestone at the western margin of the platform; (3) the San Andres formation in the Artesia field of New Mexico is correlated with the lower part of the Delaware sandstone.

INTRODUCTION

The purpose of the writers is to furnish additional information to aid in the correlation of formations on the east side of the Permian basin in West Texas with formations of similar age on the west side of the same basin in Texas and New Mexico. Voluminous literature regarding the stratigraphy of West Texas and southeastern New Mexico is available, but it is not here reviewed. Considerable difference of opinion exists about the geology of the southern end of the Permian basin, though approximately three thousand field and wildcat wells have been completed in the area.

CROSS SECTIONS

In order that some definite idea may be obtained concerning the time equivalency of the formations on, and east of, the Central Basin platform[3] and of the formations in the Delaware basin, two cross sections are offered in Plates 1 and 2.

The first of these cross sections begins with Henshaw-McMan's Owens No. 1, in Crockett County southeast of the Yates oil field, and extends along the south and west rim of the Central Basin platform to

[1]Read before the Association at the San Antonio meeting, March 20, 1931. Manuscript received, April 8, 1931.

[2]Board for Lease of University Lands, 805 San Angelo National Bank Building.

[3]Lon D. Cartwright, Jr., "Transverse Section of Permian Basin, West Texas and Southeast New Mexico," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 14, No. 8 (August, 1930), pp. 969-81.

the Ohio Oil Company's Tracy No. 1 in New Mexico. The other cross section commences with the same Henshaw-McMan's Owens No. 1 and extends along the eastern margin of the platform, ending with the Texas Company's Wilson No. 1 (Dunken dome) in New Mexico. These sections are composed of many wells whose average distance apart is not more than 7 miles. Sample logs were prepared for every well presented in the cross sections and the tie sections. Either of the two sections may be considered as located along the strike of the formations. This is a very important consideration, tending to simplify correlation, as the lithology is subject to less change. The sections are approximately 225 miles in length. In New Mexico the average distance between the two cross sections is 18 miles; in Texas it is approximately 30 miles.

CORRELATION ZONES

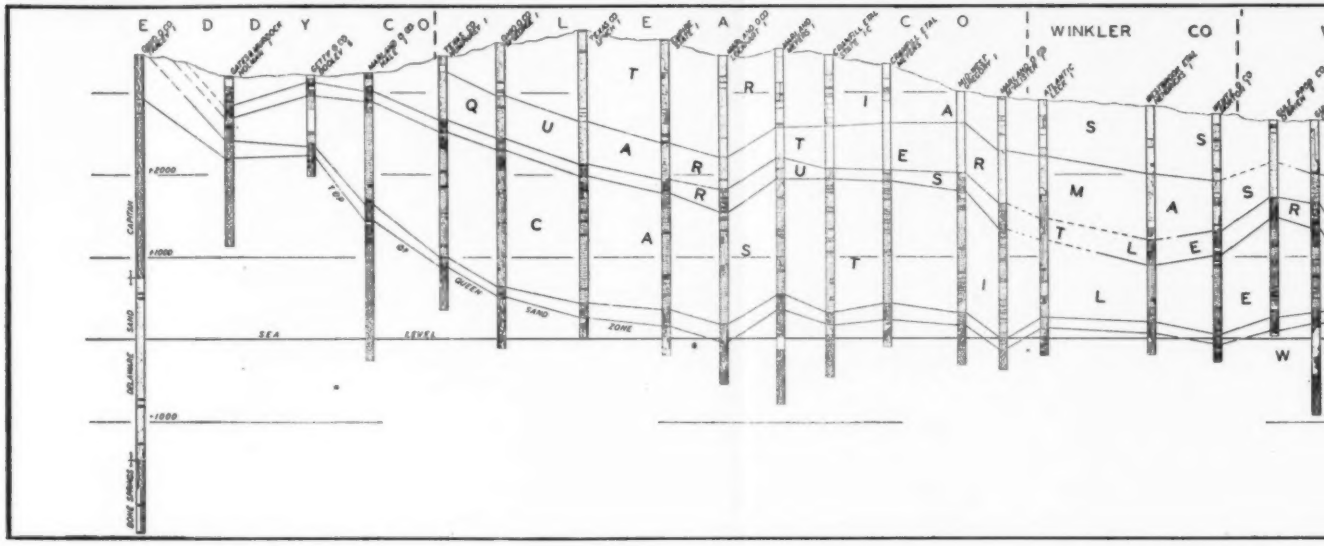
There are at least two well marked horizons or zones which may be used accurately through the greater part of the distance shown on the cross sections. The least important of these horizons is that of the Rustler. The position of the Rustler, if present, is rather obscure east of Cranfill-Reynolds *et al.* Masterson No. 1 in Pecos County, but northwest of this well it is well defined and marks the upper limits of the Castile formation.

YATES SAND ZONE

The horizon which has been the most useful for definite correlation in the entire length of the cross sections is known in Texas as the Yates sand zone and in New Mexico as the Queen sand zone. This horizon was first named the "Smith sand," by John Emery Adams during a meeting of geologists at Colorado, and was later named the Yates sand. Its description as given by Gester and Hawley[1] is here quoted.

> The top of the Yates sand occurs from 100 to 150 feet below the top of the anhydrite series, and from 500 to 550 feet above the top of the "Brown lime," the topmost member of the "Big lime" in this field. Toward the edges and away from the dome the intervals both above and below the Yates sand increase, as shown in the cross sections. Its position, away from the edges of the field, is immediately below the upper salt series.
>
> The Yates sand is practically identical lithologically with the other Permian sands of the Yates field area. It is a fine-grained, gray, drab, or oil-browned quartzose sandstone, with anhydritic or dolomitic cement. It characteristically contains conspicuous, coarse, rounded, frosted quartz grains. Thin beds of gray shale, red shale, and dolomite are commonly associated with

[1]G. C. Gester and H. J. Hawley, "Yates Field, Pecos County, Texas," *Structure of Typical American Oil Fields*, Vol. II (Amer. Assoc. Petrol. Geol., 1929), p. 488.



BULL. AMER. ASSOC. PETROL. GEOL., VOL. 15, NO. 9

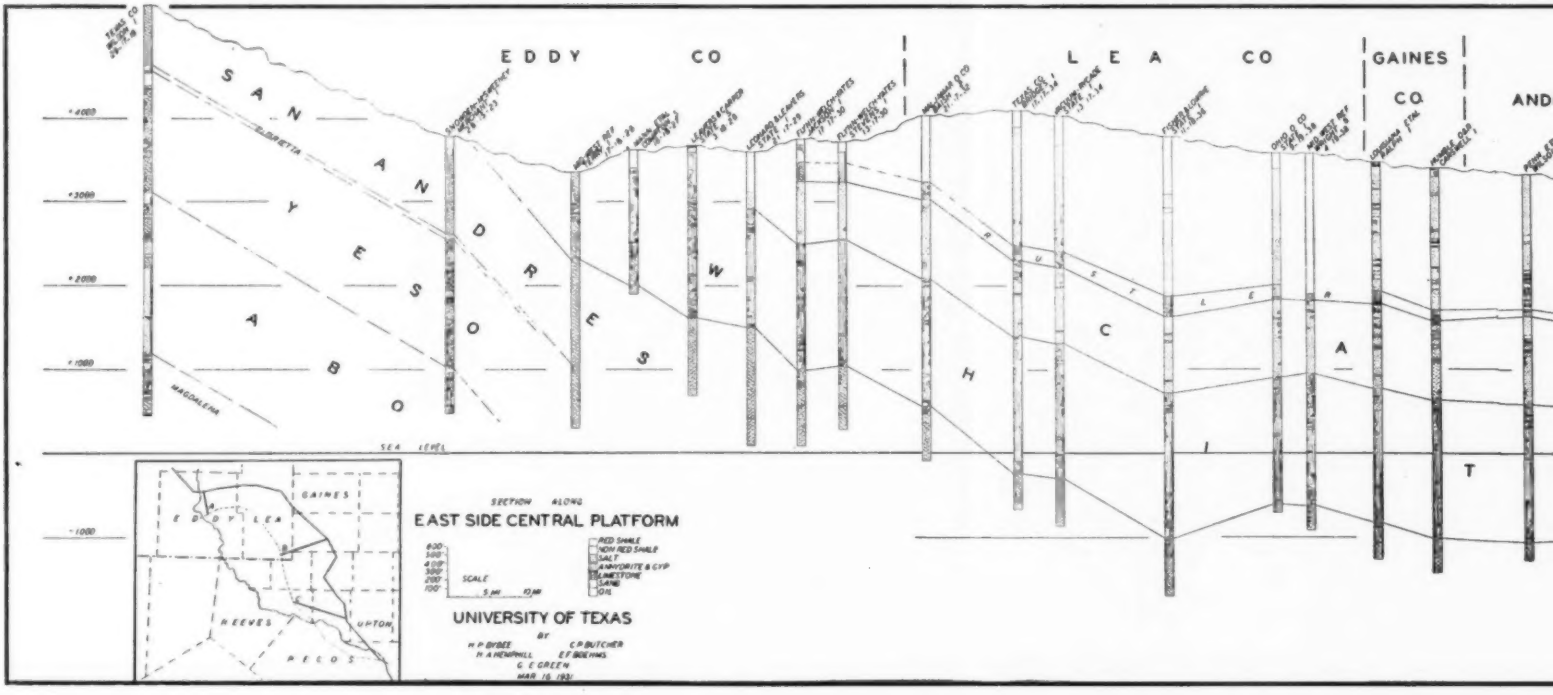


PLATE 1

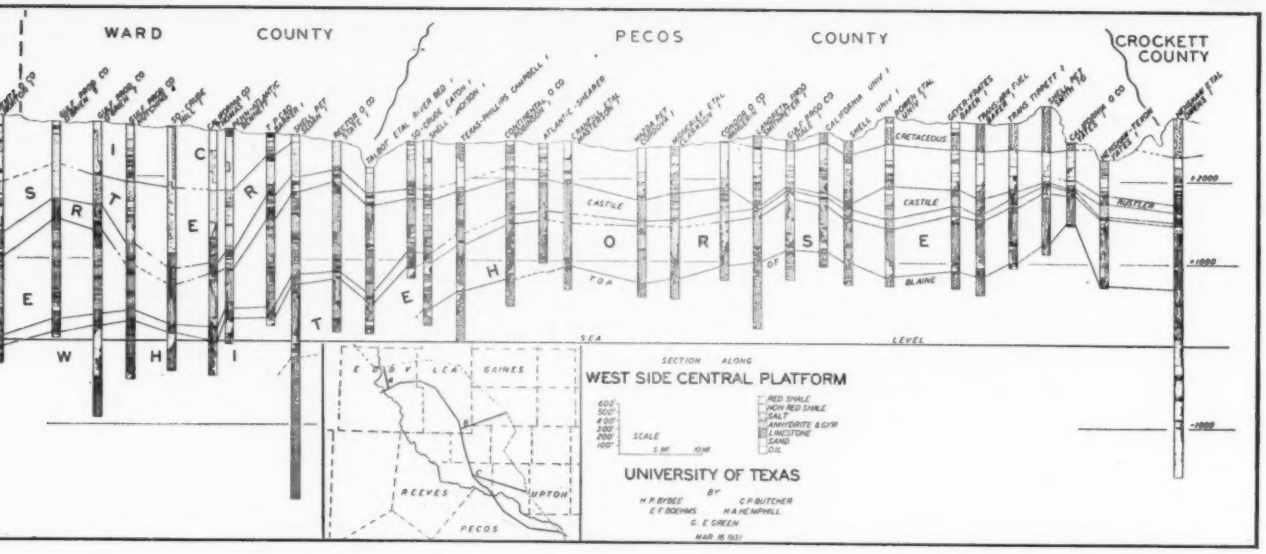
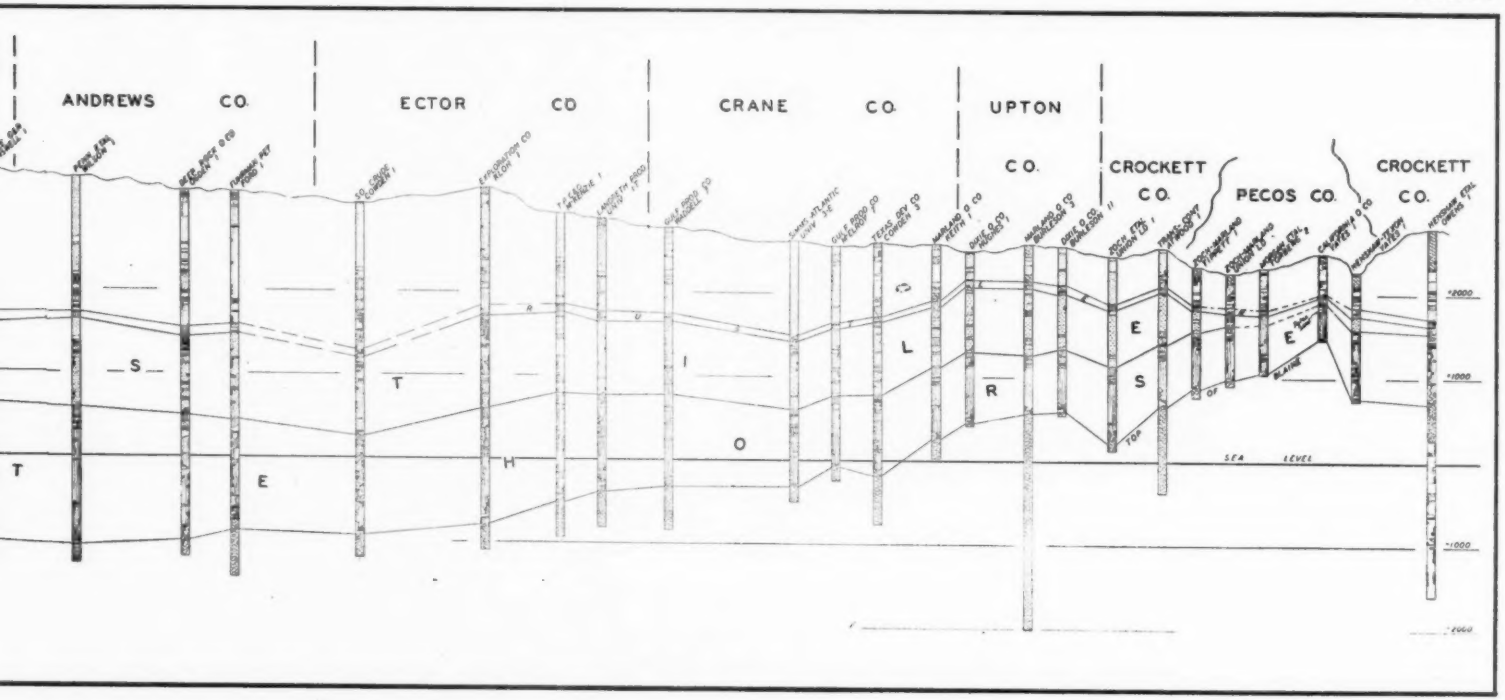


PLATE 2



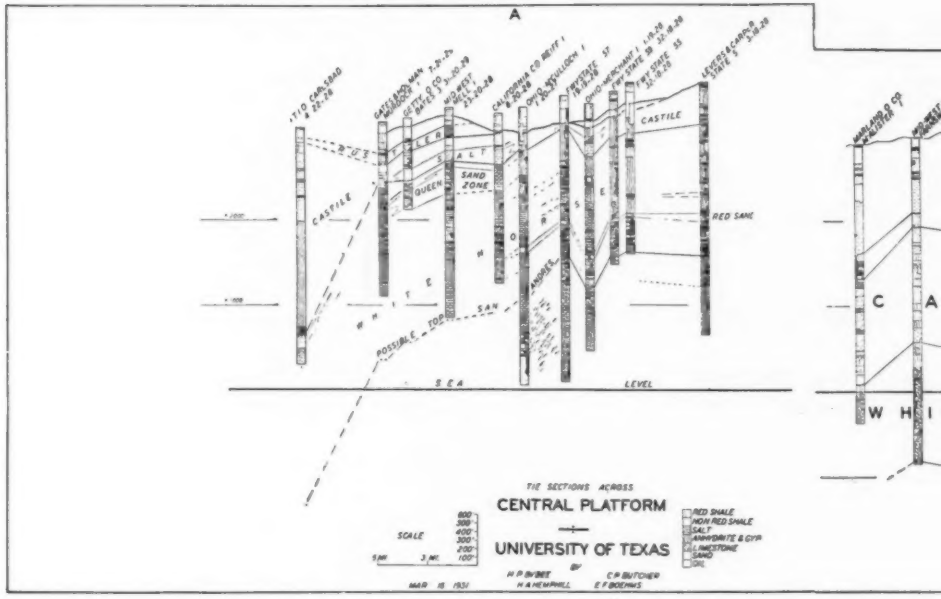
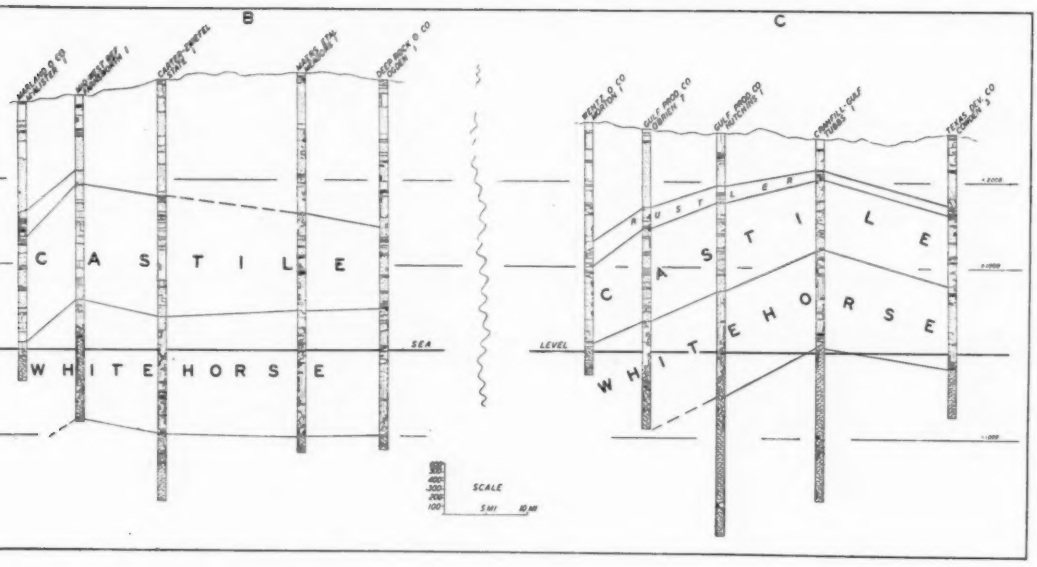

A
CASTILE
SALT
QUEEN
SAND ZONE
GRAYBURG
ANHYDRITE
RED SAND
SEA LEVEL
POSSIBLE TOP SAN
C
A
W H I
TIE SECTIONS ACROSS
CENTRAL PLATFORM
UNIVERSITY OF TEXAS
SCALE
1 MI. 1 MI.
RED SHALE
NON RED SHALE
SALT
ANHYDRITE & GYP.
LIMESTONE
SAND
OIL
MAR 15 1931
H P BYBEE
H A NEWHILL
C P BUTCHER
E T BOEHNS

PLATE 3



it. Oil and gas showings have been encountered in a great many wells in it, and salt water in a few. Its principal distinctive features are its stratigraphical position and its coarse frosted quartz grains.

Therefore, as this easily identified horizon was found in practically every set of samples examined in the cross section on the west margin of the Central Basin platform, we are accepting it as a basis for correlation from the Yates area into New Mexico.

The same typical Yates sand zone, but without the well rounded frosted quartz grains, may be followed less positively along the east side of the Central Basin platform, from the Yates area into New Mexico. The Yates sand is considered as being close to the top of the White Horse formation, correlative with the upper part of the Queen sand zone in New Mexico. The Yates sand closely follows the base of the salt in the southern end of the Permian basin.

As early as 1910, Beede[1] suggested on faunal evidence that the White Horse should be correlated with the Queen sand zone. Again in 1926 he stated[2] that White Horse sandstone fauna is correlated with the Capitan or its equivalent west of Lakewood, New Mexico.

STRATIGRAPHY OF CENTRAL BASIN PLATFORM

The two long cross sections are tied together at three places. They are tied at the western end by a cross section extending from Levers and Carper's State No. 5, Sec. 3, T. 18 S., R. 28 E., south to Gates and Holman's Murdock No. 1, Sec. 7, T. 21 S., R. 28 E. (Pl. 3, Section *A*). Another tie was extended from the Deep Rock Oil Company's Ogden No. 1, Andrews County, Texas, southwest to the Marland Oil Company's McAllister No. 1, Lea County, New Mexico (Pl. 3, Section *B*). A third tie cross section was extended from the Texas Development Company's Cowden No. 3, Crane County, to Marland-McCulloch's Morton No. 1, Winkler County (Pl. 3, Section *C*).

The western tie cross section consists of ten sample logs extending from the Artesia field on the north to the Carlsbad area on the south, a distance of only 18 miles. It is at right angles to the two long "platform" sections. Its trace, the shortest distance between them, is parallel with the strike of the Guadalupe and Sacramento mountains. It was deemed expedient to tie these sections at right angles to the structural feature

[1]J. W. Beede, "Correlation of the Guadalupian and Kansas Sections," *Amer. Jour. Sci.*, Vol. 30 (1910), pp. 131-40.

[2]J. W. Beede and D. D. Christner, "The San Angelo Formation and the Geology of Foard County," *Texas Univ. Bull. 2607*, pp. 13-14.

which forms the basis of the Capitan reef, and at a point where a maximum amount of correlative information was available. At no other place in the area discussed in this paper is an equal amount of such data available. This section is also presented in an effort to correlate the San Andres limestone on the north with a part of the Delaware basin section on the south.

The San Andres limestone section in the Artesia field ties nicely into the Flynn-Welsh-Yates' State 57 dry hole, Sec. 19, T. 19 S., R. 28 E., south of the field, a total distance of 9 miles. The exact top of the San Andres section is a point of argument among New Mexico geologists, which will not be discussed here. Three miles farther south is the Ohio Oil Company's McCulloch dry hole in Sec. 1, T. 20 S., R. 27 E., showing a limestone section underlain by a section admitted to be Delaware sandstone. It is believed that the sections of these two adjacent wells indicate a gradation from sand in the McCulloch well on the south to limestone in the Flynn-Welsh-Yates' State 57, on the north. Such a gradation correlates San Andres limestone with some part of the Delaware sandstone. It is admitted that this statement is contrary to certain published paleontological correlations made between the Sacramento, Glass, and Delaware mountains. However, if paleontological argument be followed in correlating these two wells, 3 miles apart, a tremendous south dip must be postulated from the Flynn-Welsh-Yates' State 57 well on the north to the McCulloch well on the south. Such a correlation, namely, San Andres of the Artesia area with Bone Springs of the Guadalupe-Delaware mountain section is considered questionable, for the following reasons.

1. Such a correlation tends to flatten the Bone Springs flexure, upon which the Capitan reef was formed, and does not admit of any pronounced structure or folding along the Ward-Winkler-Jal trend. Severity of folding is believed to be one contributing factor to the magnitude of the Hendrick field production.

2. Gradation of upper Delaware sandstone to Capitan limestone is generally accepted and it is believed inconsistent with logical reasoning not to assume a similar gradation between the two wells in question.

3. Paleontological correlations, as published, by no means agree. Such correlations between areas hundreds of miles apart are scarcely applicable to local correlation of near-by wells.

A close examination of this section is invited. It is believed that the San Andres limestone section of the Artesia field grades laterally into the lower part of the Delaware sandstone, and that its top may be as

high as the base of the Capitan exposed at Guadalupe Point. If it is assumed that the top of the White Horse formation is correct as extended into the Artesia area on the north platform section, it is believed to be correlative with the top of the Carlsbad formation, and in its entirety to include much of the upper Delaware sandstone. Not all reef formations in the Permian basin should be referred to as Capitan in age unless definite data are available. We believe there is insufficient evidence at this time to correlate the top of the San Andres, as previously defined, with the Bone Springs of the Delaware basin.

Even a casual observance of the two cross sections and the tie sections shows that the salt section on the eastern margin of the Central Basin platform rests on 1,200-1,500 feet of anhydrite, red sand, shale, salt, and limestone stringers below which is the "Big lime." On the western margin, the anhydrite series is much thinner or absent, permitting the salt section to come very close to the limestone section.

Cartwright[1] in his cross section assigns these beds to White Horse age, which assignment is accepted. The tie sections indicate that the anhydrite in the White Horse has graded into limestone along the western margin of the platform. Cartwright's cross section also shows this gradation. As the White Horse is Capitan in age, there is an indefinite section of limestone in the Hendricks oil field which is Capitan in age.

It is suggested that the transition from anhydrite on the eastern margin to limestone on the western margin of the Central Basin platform during White Horse time could have been caused by the platform being relatively higher on the west than on the east.

The stratigraphy of the Permian basin has been influenced by isostatic adjustments, relief features of older formations, and climatic variation. These factors have so greatly influenced sedimentation that they make various interpretations seem logical. It is hoped that this contribution will clarify rather than complicate the problem.

BIBLIOGRAPHY

1. A. L. Ackers, R. DeChicchis, and R. H. Smith, "Hendrick Field, Winkler County, Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 14, No. 7 (July, 1930), pp. 923-44.

2. John Emery Adams, "Origin of Oil and Its Reservoir in Yates Pool, Pecos County, Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 14, No. 6 (June, 1930), pp. 705-17.

3. C. L. Baker, "Exploratory Geology of a part of Southwestern Trans-Pecos Texas," *Texas Univ. Bull. 2745* (1927).

[1]Lon D. Cartwright, Jr., *op. cit.*

4. J. W. Beede, "Correlation of the Guadalupian and Kansas Sections," *Amer. Jour. Sci.*, Vol. 30 (1910), pp. 131-40.

5. ———, "Further Notes on the Structure near Robert Lee, Coke County," *Texas Univ. Bull. 1847* (1920), pp. 3-7, 1 pl.

6. ———, "Notes on the Geology and Oil Possibilities of the Northern Diablo Plateau in Texas," *Texas Univ. Bull. 1852* (1920), 40 pp., 1 fig., 7 pls. (incl. map).

7. ———, "Report on the Oil and Gas Possibilities of the University Block 46, in Culberson County," *Texas Univ. Bull. 2346* (1924), 16 pp., 2 pls.

8. ———, "The Geology of Coke County," *Texas Univ. Bull. 1850* (1921), 82 pp., 3 figs., 17 pls. (incl. map).

9. ——— and D. D. Christner, "The San Angelo Formation and the Geology of Foard County," *Texas Univ. Bull. 2607* (1926), pp. 5-17, map.

10. Emil Böse, "The Permo-Carboniferous Ammonoids of the Glass Mountains, West Texas, and their Stratigraphic Significance," *Texas Univ. Bull. 1762* (1917), 241 pp., 11 pls.

11. Lon D. Cartwright, Jr., "Subsurface Correlation Methods in the West Texas Permian Basin," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 2 (February, 1929), pp. 171-76.

12. ———, "Transverse Section of Permian Basin, West Texas, and Southeast New Mexico," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 14, No. 8 (August, 1930), pp. 969-81.

13. R. L. Clifton, "Stratigraphy of Whitehorse Sandstone; Formation Extends from Clarke County, Kansas, through Oklahoma into Panhandle Area of Texas," *Oil and Gas Jour.*, Vol. 25, No. 2 (June 3, 1926), pp. 70-74, map.

14. K. H. Crandall, "Permian Stratigraphy of Southeastern New Mexico and Adjacent Parts of Western Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 8 (August, 1929), pp. 927-44.

15. N. H. Darton, "'Red Beds' and Associated Formations in New Mexico, with an Outline of the Geology of the State," *U. S. Geol. Survey Bull. 794* (1928).

16. N. H. Darton and J. B. Reeside, "Guadalupe Group," *Bull. Geol. Soc. Amer.*, Vol. 37, No. 3 (September, 1926), pp. 413-28, 4 figs., 6 pls. (incl. map).

17. W. M. Davis, "The Coral Reef Problem," *Amer. Geog. Soc. Spec. Pub. 9* (1928), 596 pp., 227 figs.

18. E. C. Edwards, "Stratigraphic Position of the Big Lime of West Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 2, No. 7 (July, 1927), pp. 721-28.

19. G. C. Gester and H. J. Hawley, "Yates Field, Pecos County, Texas," *Structure of Typical American Oil Fields*, Vol. II (Amer. Assoc. Petrol. Geol., 1929), p. 488.

20. George H. Girty, "The Guadalupian Fauna and New Stratigraphic Evidence," *Annals New York Acad. Sci.*, Vol. 19, Pt. 1 (1909), pp. 135-47.

21. Charles N. Gould and Robin Willis, "Tentative Correlations of the Permian Formations of the Southern Great Plains," *Bull. Geol. Soc. Amer.*, Vol. 38 (September, 1927), pp. 431-42.

22. Ray V. Hennen and R. J. Metcalf, "Yates Oil Pool, Pecos County, Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 12 (December, 1929), pp. 1509-56.

23. H. W. Hoots, "Geology of a Part of Western Texas and Southeastern New Mexico with Special Reference to Salt and Potash," *U. S. Geol. Survey Bull. 780* (1925), pp. 33-126, 1 fig., 15 pls. (incl. maps).

24. E. L. Jones, Jr., and Russell C. Conkling, "Basement Rocks in Shell-Humphreys Well, Pecos County, Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 14, No. 3 (March, 1930), pp. 314-16.

25. Charles Keyes, "Guadalupian Reef Theory," *Pan-Amer. Geol.*, Vol. 52, No. 1 (August, 1929), pp. 41-60, 3 pls.

26. Philip B. King, "The Geologic Structure of a Portion of the Glass Mountains of West Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10, No. 9 (September, 1926), pp. 877-84, 2 figs., 1 pl. (map).

27. ———, "The Geology of the Glass Mountains," *Texas Univ. Bull. 3038* (1930).

28. ———, "The Pennsylvanian and Permian Stratigraphy of the Glass Mountains," *Texas Univ. Bull. 2801* (1928), pp. 109-45.

29. E. Russell Lloyd, "Capitan Limestone and Associated Formations of New Mexico and Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 6 (June, 1929), pp. 645-59.

30. ———, "Origin of Porosity in Reef Limestone or Dolomite," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 9 (September, 1929), p. 1219.

31. C. L. Mohr, "Secondary Gypsum in Delaware Mountain Region" (discussion), *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 10 (October, 1929), p. 1395.

32. Sidney Powers, "Buried Ridges in West Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 11, No. 10 (October, 1927), pp. 1109-15.

33. "Symposium on Pennsylvanian and Permian Stratigraphy of Southwestern United States," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 8 (August, 1929), pp. 883-1063.

34. J. A. Udden, "Fossils from the Word Formation of West Texas" (abstract), *Bull. Geol. Soc. Amer.*, Vol. 38, No. 1 (March, 1927), p. 159.

35. W. A. J. M. van der Gracht, "Barrier Reefs in West Texas Basin" (discussion), *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 10 (October, 1929), p. 1397.

36. W. E. Wrather," Notes on the Texas Permian," *Bull. Southwestern Assoc. Petrol. Geol.*, Vol. 1 (1917), pp. 93-106.

GEOLOGICAL NOTES

SUPPOSED MARINE JURASSIC (SUNDANCE) IN FOOTHILLS OF FRONT RANGE OF COLORADO[1]

The record by F. V. Hayden, of the occurrence of marine Jurassic rocks in the northern foothills of the Front Range of Colorado, has acquired the respectable age of 62 years without serious attack on its validity. Several geologists have, indeed, expressed considerable perplexity at their failure to confirm Hayden's statement, but most have accepted it at face value. It is remarkable, however, that only one geologist since Hayden has presented positive support. The late W. T. Lee, in a fairly recent paper, seemingly confirmed the earlier record completely, citing identifications of fossils by the present writer. The southern foothills have not figured conspicuously in the question, for most writers who deal with them have assumed the absence of marine Jurassic beds, though some writers have suggested that a nonmarine equivalent of the marine deposits may occur.

Several years ago the writer began to have doubts about the current interpretation of the Jurassic part of the Front Range section. Not until last summer, however, did the accumulation of data in other areas make it seem desirable to re-examine the exposures along the Front Range. This re-examination has demonstrated to the writer's satisfaction that the report of marine, fossiliferous Jurassic deposits there is erroneous, though the basal sandstone of the Sundance does extend southward into Colorado, perhaps as far as Loveland.

A brief review of the literature is of interest.

Hayden[2] in 1869 described the section in Box Elder Creek, near the Colorado-Wyoming boundary, and noted the following units, quoted, for greater convenience, from top down, in the reverse of the order of the original report.

5. Sandstone and laminated arenaceous material, varying in color from a dirty brown to grayish white, with layers of fine grayish white sandstone. At least 200 feet.

[1]Published by permission of the acting director of the United States Geological Survey.

[2]F. V. Hayden, "Report on Colorado and New Mexico," *U. S. Geol. Survey Terr., 3d Ann. Rept.* (1869), p. 19; reprint (1873), p. 119.

4. Ashen-brown nodular or indurated clay, with deep, dull purple bands; with some layers of brown and yellow fine-grained sandstone, undoubtedly the usual Jurassic beds..... Near the base of these beds are thin layers of a fine-grained grayish calcareous sandstone, with a species of *Ostrea* and fragments of *Pentacrinus asteriscus*. Scattered through this bed are layers or nodules of impure limestone. 150 to 200 feet.

3. A bed of grayish yellow rather massive sandstone. 60 feet.

2. Yellow or reddish yellow sandstone, massive. 60 feet.

1. Brick-red sandstone with irregular laminae and all the usual signs of currents or shallow water. Some of the layers are more loosely laminated than others, thus causing projecting portions. 300 to 400 feet.

Hayden regarded his units 4 and 5 as Jurassic, but noted that

the most abundant and most characteristic fossil in the Jurassic beds..... *Belemnites densus*.....has not been observed south of Lake Como, west of the Laramie Range. As we proceed southward these Jurassic beds become thinner and more obscure, so that it often becomes a matter of doubt whether they exist at all.

Hayden's unit 5 seems surely to be the Dakota sandstone of modern usage and his unit 1 the Lykins formation. His units 2, 3, and 4 include the Morrison and any possible representative of the Sundance.

Marvine[1] in 1874 reported for the Front Range region that

in the so-called Jurassic and Triassic.....not a single fossil has rewarded the summer's search.....On Box Elder Creek, north of the Big Thompson, Dr. Hayden found some beds.....containing a species of *Ostrea* and fragments of *Pentacrinus asteriscus*, a characteristic Jurassic fossil. These beds are the same that occur near and above the cherty limestone in the sections which I have described as Jurassic and seem to settle the correctness of their assumed age as decisively as possible without the direct finding of fossils in the very region under discussion.

Darton[2] in 1904 expressed the opinion that "the Sundance formation extends only a few miles into Colorado from the northward, finally ending by thinning out." He quoted Hayden's record of marine Jurassic fossils and Hayden's suggestion that the limestones at the base of the Morrison, as recognized by Darton, are an extension of the marine Jurassic. Darton rejected the suggestion, however, with the remark that he felt "certain that all these [limestones] in the Front Range are of Morrison age."

[1]A. R. Marvine, "The Sedimentary Rocks East of the Front Range," *U. S. Geol. Survey Terr., 7th Ann. Rept.* (1874), p. 105.

[2]N. H. Darton, "Comparison of the Stratigraphy of the Black Hills, Bighorn Mountains, and Rocky Mountain Front Range," *Bull. Geol. Soc. Amer.*, Vol. 15 (1904), pp. 424, 442.

Darton[1] in 1905 again interpreted Sundance as extending only into northern Colorado and repeated Hayden's record of marine fossils. He noted plentiful fresh-water algae in the lower Morrison limestones, but did not describe them.

Henderson[2] in 1908 reported that he and his associates had not found any fossils in Box Elder Valley except *Valvata scabrida* Meek and Hayden, a fresh-water gastropod, in Morrison limestone. He adds that the yellow sandstone (part of Hayden's units 2 and 3) does not seem to persist south of Cache La Poudre River; also notes a then prevalent opinion that marine Jurassic does not exist in the Denver basin and thence southward, but lays the matter aside as in need of further study.

Butters[3] in 1913 quotes earlier writers and notes that "no one since [Hayden] appears to have been able to locate that [Sundance] fossil horizon." He describes the rocks immediately above the Lykins formation from the Wyoming line to Cache La Poudre River as constituting

> a series of massive sandstones from 100 to 150 feet thick, the lower two-thirds of which is pink, grading to yellow, and the upper one-third yellow to creamy white. There is an abrupt and very pronounced lithological break between the soft, brick-red Lykins.....and the sandstone, but no discovered unconformity, either angular or erosional. This abrupt change.....is widespread.

Butters reported no identifiable fossils, but, perhaps because of the old record of fossils and similarity to beds in Wyoming, thought the upper third of the sandstones to be the Sundance. He did not, however, finally exclude the lower two-thirds, though he makes no definite assignment of them. He quotes Henderson as considering the lower pink sandstone distinct from the Lykins and related to the overlying yellow sandstone. Butters assigned the beds above the sandstones to the Morrison and reported from them *Unio* and fresh-water algae, without definite description of the fossils.

Mook[4] in 1916 summarized the literature dealing with the Morrison of the northern Front Range, adding no new data. He also described at first hand the occurrences in the southern Front Range, where he found the Morrison to rest directly on pre-Jurassic beds.

[1]N. H. Darton, "Geology and Underground Water Resources of the Central Great Plains," *U. S. Geol. Survey Prof. Paper 32* (1905), pp. 72, 82, 96, 163.

[2]Junius Henderson, "The Foothills Formations of North Central Colorado," *Colorado Geol. Survey 1st Ann. Rept.* (1908), pp. 170-71.

[3]R. M. Butters, "Permian or Permo-Carboniferous of the Eastern Foothills of the Rocky Mountains in Colorado," *Colorado Geol. Survey Bull. 5* (1913), pp. 67, 70.

[4]C. C. Mook, "A Study of the Morrison Formation," *New York Acad. Sci. Ann.*, Vol. 27 (1916), pp. 45, 111.

Lee[1] in 1918 in a general discussion presented a map which indicates most of Colorado as the site of non-marine deposition in Upper Jurassic time. He suggests that the pink and yellow sandstones of the foothills sequence are "some part of the La Plata." At another place, he says of shale and sandstone above the Lykins:

> I am inclined to regard them as the attenuated edge of the Nugget or lower La Plata sandstone. It seems probable that the limestone and gypsum at or near this horizon farther south may represent the extension of the Jurassic sea beyond the localities where its waters were suitable for the support of marine organisms.

Henderson[2] in 1920 revised his report of 1908, adding to it, among other items, a note that the

> harder, massive sandstone, 100 feet or more in thickness, pink in the lower half, grading through yellowish to creamy-white above.....probably includes the beds referred to the Sundance by Darton.....It has a tendency to form cliffs, in places weathering into rounded forms, especially southward. It occurs at least as far south as Loveland, but is absent in the Boulder district.

Lee,[3] in 1927, as a result of field work done about 5 years earlier, discussed the Morrison and associated beds in the Front Range at considerable length. He tentatively correlated with the Upper Triassic Jelm formation the unfossiliferous orange-colored sandstone resting on the Lykins in the northern foothills. On the basis of lithologic features and fossils from Box Elder Canyon identified at that time by the present writer as *Pentacrinus* sp. (probably *P. asteriscus* Meek and Hayden) and *Pleuromya* sp., he assigned to the marine Jurassic the light-colored sandstones and the limestones resting on them. The remainder of the series of rocks up to the Dakota Lee assigned to the Morrison. He suggested that most of the persistent limestone zone of the foothills region that had generally been included in the Morrison formation should be placed in the Sundance and with it the thick, bedded gypsum present at some localities south of Denver. He did not identify his Jelm (?) sandstone south of Loveland.

[1]W. T. Lee, "Early Mesozoic Physiography of the Southern Rocky Mountains," *Smithsonian Misc. Coll.*, Vol. 69 (1918), No. 4, pp. 11, 16, 17.

[2]Junius Henderson, "The Foothills Formations of North-Central Colorado," *Colorado Geol. Survey Bull. 19* (1920), pp. 79, 80.

[3]W. T. Lee, "Correlation of Geologic Formations between East-Central Colorado, Central Wyoming, and Southern Montana," *U. S. Geol. Survey Prof. Paper 149* (1927), pp. 14-16, 23, 25-40, pls. 24-26.

Lee's section of the rocks between the Lykins and the Dakota in Box Elder Canyon is of particular interest for its fossils and for comparison with Hayden's section previously quoted. It is as follows.

Dakota group.
Unconformity.
Morrison formation: Shale, variegated, with sandy concretions in upper part and layers of sandstone in lower part. 200 feet, about.
Sandstone, gray, soft, thin bedded; contains small pebbles and dinosaur bones. 5 feet.
Unconformity by erosion; upper part of Sundance absent.
Sundance formation (lower fossiliferous zone with *Pentacrinus* sp., probably *P. asteriscus* Meek and Hayden, undetermined pelecypods, and *Pleuromya* sp. undet.):
Shale, with several layers of shaly sandstone. 24 feet.
Limestone, gray, soft. 3 feet.
Shale, pink to gray, sandy to limy. 20 feet.
Limestone, gray, sandy. 4 feet.
Sandstone, blue brittle limestone, and shale, with fossils. 40 feet.
Sandstone, lemon-yellow, evenly bedded, ripple marked. 5 feet.
Shale, pink to gray. 7 feet.
Sandstone, pink. 2 feet.
Shale, red. 3 feet.
Sandstone, yellowish pink, ripple marked. 5 feet.
Sandstone, massive, ledge making, lemon-yellow. 16 feet.
Local erosional unconformity.
Sandstone, buff, massive, cliff making, variable in thickness, with cross-bedding of eolian type. 20 to 100 feet.
Jelm (?) formation: Sandstone, massive, cross-bedded, generally orange-colored to red but gray in some places near the top. 122 feet.
Erosional unconformity.
Lykins formation.

Coffin[1] in 1929 gave a generalized section for Owl Creek, showing the same units essentially as those adopted by Lee and with the following thicknesses: Morrison, 200 feet; Sundance, 150 feet, "marine beds probably absent;" Jelm (?), 50 feet. Coffin says:

The Marine Sundance of Central Wyoming as shown in the Douglas section, thins to the south and is not found south of Big Thompson River near Loveland.

Lovering[2] in 1929 accepted the report of marine "Jurassic beds of the Sundance formation" along the northeastern border of the Front

[1]R. C. Coffin, in *Guide-book to 3d Annual Field Conference of the Kansas Geological Society* (1929), pp. 79, 81.

[2]T. S. Lovering, "Geologic History of the Front Range, Colorado," *Colorado Sci. Soc. Proc.*, Vol. 12 (1929), p. 84.

Range, citing them as predominantly sandstone and unconformable on the underlying Lykins formation. He also cited the upper members as vanishing southward and leaving only the basal sandstone along most of the eastern margin of the Front Range.

Johnson[1] in 1930 attributed to I. A. Keyte a record of marine Sundance fossils in "limestone near the base of the Morrison" at Colorado Springs.

From the foregoing resumé of the literature the following items may be gathered. 1. The section above the Lykins formation and below the Dakota sandstone in the northern foothills of the Front Range contains a massive, cross-bedded basal sandstone, described as orange or pink in color; and a group of shales, containing in the lower part many gray limestone layers and showing in the upper part a variegated coloring. 2. The sandstones do not extend very far south. 3. No one after Hayden (1869) reported marine fossils in the section until Lee (1927) published the present writer's identifications, the value of both records depending chiefly on the degree of certainty in the identification of *Pentacrinus*. 4. Darton, however, reported fresh-water algae; Henderson reported *Valvata scabrida*, a Morrison species; and Butters reported *Unio* and algae—these three seemingly all from the same part of the section as the marine fossils of Hayden and Lee.

The following observations apply to areas outside east-central Colorado.

In eastern Utah it has been found convenient to divide the accepted Upper Jurassic sequence into several units, named, in ascending order, the Carmel formation, the Entrada sandstone, the Curtis formation, and the Summerville formation.[2] The first and third have yielded marine fossils but do not extend far eastward. The second, the Entrada sandstone, has yielded no fossils but is known to pass eastward into Colorado as part of the "La Plata sandstone" of Cross.[3] It has a characteristic lithology and ordinarily exhibits the type of cross-bedding thought by many to indicate eolian origin. Above the Summerville lies the Morrison formation.

[1]J. H. Johnson, "The Geology of the Golden Area, Colorado," *Colorado School of Mines Quart.*, Vol. 25 (1930), No. 3, p. 11.

[2]James Gilluly and J. B. Reeside, Jr., "Sedimentary Rocks of the San Rafael Swell and Some Adjacent Areas in Eastern Utah," *U. S. Geol. Survey Prof. Paper 150* (1928), pp. 73-80.

[3]A. A. Baker, C. H. Dane, and J. B. Reeside, Jr., "Correlation of the Jurassic Formations of Southern Utah, Northern Arizona, Northwestern New Mexico, and Southwestern Colorado" (abstract), *Bull. Geol. Soc. Amer.*, Vol. 41 (1930), p. 87.

In Wyoming all the accepted Upper Jurassic beds are included in the Sundance formation, which has been interpreted by most recent writers[1] as including a basal unfossiliferous sandstone unit and overlying chiefly marine beds. It is the present writer's opinion that the basal sandstone of the Sundance is approximately equivalent to the Entrada sandstone of Utah and western Colorado. Above the Sundance lies the Morrison formation.

During the summer of 1930 J. S. Williams and the present writer visited several localities in west-central Colorado along Colorado River and its tributaries. At nearly all of these the Entrada sandstone rests with very sharp but only gently sinuous contact on the Triassic Dolores formation. The Entrada is conformably overlain at several localities, especially toward the north and northeast, by a thin zone of marine beds containing a normal Sundance fauna and toward the east becomes orange or pinkish and exceedingly like the sandstone just above the Lykins in the eastern border of the Front Range. The contact of the sandstone and marine beds is gradational. Above the marine beds and separated from them by only an arbitrary boundary, lie at some places gray shales with many limestone layers, at other places a variable light-colored sandstone followed by gray shales and limestones. These pass upward into the ordinary varicolored shales and sandstones of the upper Morrison. At every locality examined a profusion of algal remains of several types occurs in the limestones, the most plentiful and most striking type being a relative of *Chara* and having the general structure of a wire rope—a central strand and an outer layer of half a dozen similar strands twisted around it, the whole approximately 2 millimeters in diameter. A few fresh-water gastropods, all Morrison species, were found with the algae, but ordinarily no other fossils were seen. Southward the marine zone disappears and then the Entrada itself, leaving the limestone zone of the Morrison directly on pre-Jurassic rocks.

Returning to east-central Colorado, J. S. Williams and the writer visited in October, 1930, several localities along the Front Range, part in company with I. A. Keyte and part in company with Roy G. Coffin. The similarity of the sections along the Front Range to those in west-central Colorado is very noticeable. The limestones described by the writers cited in the review of literature occur all along the Front Range and contain in every section examined the same species of algae as do those of west-central Colorado. In addition there are several Morrison

[1]See, for example, J. A. Bartram, "Triassic-Jurassic Red Beds of the Rocky Mountain Region, Another Discussion," *Jour. Geol.*, Vol. 38 (1930), pp. 335-45.

invertebrates. In the Colorado Springs region these limestones rest directly on a thick gypsum bed that has ordinarily been put into the Lykins. Professor Keyte has expressed the opinion that the gypsum is closely related to the overlying deposits and sharply separated from the underlying formation.[1] With this opinion the writer agrees completely, recalling several places in other areas where bedded gypsums occur at the base of the Morrison formation. Along the northern Front Range the sequence is exceedingly like that west of the mountains except that, as noted in the following paragraphs, no marine zone can be identified. The orange or pink sandstone that Lee called Jelm (?) seems to the writer almost surely Entrada and part of the Upper Jurassic Sundance formation, fading out southward as its counterpart does west of the mountains. Part of the overlying lighter-colored sandstone may also belong with it. Part of the light-colored sandstone and the limestone zone contain only Morrison fossils and are surely Morrison.

Against this interpretation stand the records of marine fossils by Lee and Hayden. The present writer has recently re-examined the specimens determined by him for Lee in 1922 as "*Pentacrinus* sp., probably *P. asteriscus*," and "*Pleuromya* sp." and finds that the "*Pentacrinus*" is nothing more than the abundant *Chara*-like alga, which in these particular specimens happens to simulate poorly preserved crinoid stems; and that the "*Pleuromya*" and other previously undetermined pelecypods are *Unio felchi* White and *U. iridoides* White. These are accompanied by a species of *Limnaea* not previously noted. All are Morrison species. It is the writer's grave suspicion that Hayden in 1869 had only similar material, that his "*Ostrea* sp." really was *Unio* sp. and his "*Pentacrinus asteriscus*" was the deceptive algal form. Hayden's specimens are no longer available and no direct check is possible, but it is difficult to believe that the repeated searches for marine fossils in the outcrops on Box Elder Creek and elsewhere would otherwise have been so fruitless.

Thus, in summary, it is the writer's opinion that the records of marine Jurassic fossils in the northern Front Range are erroneous; that the identification of Sundance in the Front Range must rest chiefly on non-biologic criteria, that is, the similarity of the orange sandstone, Lee's Jelm (?), to the Entrada sandstone and the basal Sundance; that southward from the place near Loveland at which this sandstone disappears only Morrison remains between the Dakota and the older rocks. There is no certain evidence of marine origin of any of the sandstones. They belong rather to the large group of cross-bedded sandstones which

[1]Oral communication.

have been ordinarily interpreted as eolian. Most of the beds which have been called Sundance in the Front Range are really Morrison, though to the writer that does not necessarily mean a great difference in age. There are unconformities beyond question within the Sundance and Morrison formations, but none of them can be recognized in very large areas and it seems very doubtful that any of them are of more than minor importance.

JOHN B. REESIDE, JR.

U. S. GEOLOGICAL SURVEY
WASHINGTON, D. C.
June 4, 1931

SILICIFIED SHELL FRAGMENTS AS AN INDICATION OF UNCONFORMITY

The weathering *in situ* of many Paleozoic limestones, with consequent development of residual clay, has been observed to result in a peculiar type of silicification of the included fossils. The shells in the limestone matrix are wholly calcareous, the same forms in the overlying residuum wholly silicified, and those individuals which are partly weathered from the limestone are silicified only in that part which projects into the weathered zone.

On the surface of the shell occur many of the so-called "beekite rings," described and figured by Bassler.[1] These are small, doughnut-like circlets of bluish gray to white, opaque or translucent quartz. The size and the completeness of the ring are variable. The larger rings seem to occur on large shells.

Though these rings have been noticed by the writer only in rocks of Paleozoic age, there seems to be no reason why they may not occur also in later rocks of similar lithology. They are especially common in the Plattin of Missouri, the Platteville of Iowa, certain Chester limestones of Illinois, Silurian limestones of Iowa, the Chimneyhill limestone of Oklahoma, and the upper Arbuckle (Cotter?) of the Wichita Mountain region. It is less common in the upper beds of the Kimmswick of Illinois and Missouri.

H. S. McQueen has shown the writer siliceous residues from wells in Missouri, in which are found fragments of shells bearing these rings. All the samples were taken from beds immediately below an unconformity.

[1] R. S. Bassler, *Proc. U. S. Nat. Mus.*, Vol. 35 (1908), p. 135.

The shell fragments of brachiopods, gastropods, and cephalopods found in drill cuttings commonly are too small for identification, and the presence of an unconformity in a continuous series of limestones can be detected only by reference to the more minute forms or to lithology. It is believed that the finding of silicified shell fragments, bearing beekite rings, may be considered proof that an erosional zone has been entered, though the lithologic change is not marked, nor diagnostic fossils present. The ordinary criterion for determining that a fossil has been "re-worked" is degree of rounding, or wear, but this demands the occurrence of transportation or wave action. Beekite rings develop merely under subaerial weathering.

Little work seems to have been done on the problem of origin of beekite rings, and no definite statement has been found concerning the original character of limestone, of shell material, or of weathering conditions necessary for their formation. It seems worthy of further study, but despite lack of knowledge regarding the process involved, the fact of occurrence only in a weathered zone seems well established. Obviously a study of siliceous residues affords the best opportunity for detecting this type of silicification in well cuttings.

J. V. HOWELL

PONCA CITY, OKLAHOMA
July 11, 1931

ERRATA

In J. L. Tatum's "General Geology of Northeast Mexico," in the August *Bulletin*, page 872, first paragraph, third line, "Cavings" should be *Cavins*; also, page 892, Bibliography reference 6, same correction. On page 877, fourth line from bottom, "*popocapensis*" should be *potapacoensis*.

DISCUSSION

BEARING OF CAP ROCK ON SUBSIDENCE ON CLAY CREEK SALT DOME, WASHINGTON COUNTY, TEXAS, AND CHESTNUT DOME, NATCHITOCHES PARISH, LOUISIANA[1]

Lahee in his discussion of the paper by Heath, Waters, and Ferguson[2] on the Clay Creek dome says:[3]

> The fact that a maximum thickness of cap rock has been found in the central basin does not seem to justify the theory of solution of the salt as a cause of the downsinking.

This statement seems to be based on a failure to recognize the probable mode of origin of the anhydrite cap rock and thereby introduces an unnecessary difficulty into the interpretation of the conditions at Clay Creek. As I am responsible for having promoted an interpretation of the origin of cap rock[4] which I have since rejected[5] for those cap rocks which I have studied, I want to call attention here to the bearing of the probable mode of origin on the post-Jackson subsidence at Clay Creek, and the post-Claiborne (?) subsidence on the Chestnut dome.[6] As the information about the Clay Creek dome is by far the fuller, I shall restrict my discussion to that dome.

The theory which I am advocating for the origin of cap rock not only permits, but requires, the solution of the top of the salt core for the formation of the anhydrite cap rock, as it is the anhydrite in the salt, both that disseminated in the "annual layers" and that occurring as thicker beds, which, it is assumed, builds up the cap rock. The evidence in support of this interpretation is presented more fully in a paper now in preparation and will not be elaborated here. But any one who will look at cross sections of German salt domes (like that reproduced in Figure 11 of Barton's paper on American salt

[1]Published with the permission of the acting director, U. S. Geological Survey.

[2]F. E. Heath, J. A. Waters, and W. B. Ferguson, "Clay Creek Salt Dome, Washington County, Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 15, No. 1 (January, 1931), pp. 43-60.

[3]F. H. Lahee, "Clay Creek Salt Dome, Washington County, Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 15, No. 3 (March, 1931), p. 283.

[4]Marcus I. Goldman, "Petrography of Salt Dome Cap Rock," *Geology of Salt Dome Oil Fields* (Amer. Assoc. Petrol. Geol., 1926), pp. 50-86.

[5]*Idem*, "Features of Gypsum-Anhydrite Salt Dome Cap Rock" (abstract), *Bull. Geol. Soc. Amer.*, Vol. 40, No. 1 (March, 1929), pp. 99-100 and discussion of L. S. Brown's paper, "Cap-Rock Petrography," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 15, No. 5 (May, 1931), pp. 523-27.

[6]F. H. Lahee, "Chestnut Dome, Natchitoches Parish, Louisiana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 15, No. 3 (March, 1931), pp. 277-78.

dome problems[1]) and consider the immense volume of anhydrite-bearing folds obviously decapitated by the flat top or "salt table" as Barton has called it, in his translation of Stille's article,[2] must realize that a large volume of anhydrite must have been freed during the formation of the salt table by solution of the top of the salt plug, and that this anhydrite accounts adequately for the anhydrite cap rock on the German domes. As most American salt cores have this same general form and intrusive character and probably have similar flat tops,[3] their anhydrite caps may be assumed to have originated in the same way; and the petrography of the anhydrite caps I have examined fits this assumption.

That the anhydrite cap should be 550 feet thicker in hole 8*a* near the center of the dome than it is in hole 6, obviously on the flank or at the edge of the flank of the salt core, is, I believe, an ordinary condition and readily explained if we assume a tendency for solution to form a relatively flat salt table. The most rapid flow of the plastic salt core would naturally be at the center, where the frictional resistance of the flanking sediments was least. In maintaining a flat top, the greatest amount of solution and the thickest accumulation of residual anhydrite would therefore be in that position. The greater thickness might also be the result of the presence of more anhydrite in the folded salt series of the salt core below the thicker part of the cap. There is, as I see it, therefore, nothing anomalous about the conditions at Clay Creek.

The amount of solution indicated at Clay Creek may, at first glance, seem excessive; but simple calculations, on the basis of the theory presented in the previous paragraph, of the origin of the anhydrite cap rock, show that it is not. We know little about the stratigraphic composition of the salt of Gulf Coast salt domes. But I know of no evidence that beds of anhydrite have been encountered on drilling into the salt. The presence of fragments of such beds in the anhydrite cap rock of many Gulf Coast domes is evidence that they are present in the salt; but the fact that they have not been encountered in drilling into the salt indicates that they are, as one would expect, not very plentiful. It is reasonable to assume, from all the evidence available, that the so-called "annual layers," with their dividing surfaces strewn with anhydrite crystals, are generally present in the salt of Gulf Coast salt domes, as they are known to be in the salt of the Five Islands domes and in other sedimentary salt bodies. But the proportion of anhydrite on these layers is also relatively slight. If we assume, however, the probably very excessive proportion of 10 per cent of anhydrite in the Clay Creek salt core, the indicated solution of

[1]Donald C. Barton, "The American Salt-Dome Problems in the Light of the Roumanian and German Salt Domes," *Geology of Salt Dome Oil Fields* (Amer. Assoc. Petrol. Geol., 1926), p. 194.

[2]Hans Stille, "The Upthrust of the Salt Masses of Germany," *Geology of Salt Dome Oil Fields* (Amer. Assoc. Petrol. Geol., 1926), p. 151.

[3]*Op cit.*, figures *passim*.

a column of salt 1,100 feet high would account for only about 120 feet[1] of the 1,050 feet of anhydrite cap rock in well 8*a* of Lahee's Figure 1. To the total thickness of the anhydrite cap, moreover, should probably be added the 137-foot thickness of the true "limestone" (calcite) cap which, as Brown has shown,[2] is probably all gypsum-anhydrite cap replaced by calcium carbonate.

However, while these calculations show that the solution of 1,100 feet of salt is a very small part of the total solution of the salt core required to account for the cap rock present on the Clay Creek dome, they prove nothing as to the actual amount of solution that occurred in the lowering of the top of the salt core 1,100 feet, during the deposition of the Oligocene and Miocene in the position of well 8*a* of Lahee's Figure 1, for these calculations are based on the assumption of a static salt core. But actually the movement of the top of the salt core is the algebraic sum of the upward flowage of the core and the removal of salt from the top by solution; and, theoretically at least, there may be all degrees of relative dominance of one or the other, from solution with no upward movement, to upward movement with no solution, and between the two a stationary top with both processes very active and consequent growth of the cap rock without vertical movement.

The recognition of these considerations helps toward the understanding of many complex relations, such as those so interestingly depicted in the papers under discussion. (See especially Figure 5 of Heath, Waters, and Ferguson's paper.)

Further analysis, with this in mind, of the section in wells 8*a* and 6 of Lahee's Figure 1, in their bearing on movement of the top of the salt core, also leads to some modification of Lahee's results, not important quantitatively, but helping toward a realization of the possible complexity of the movements involved. If we accept the idea that the salt table moves up and down essentially as a whole, it is not probable that there was 1,100 feet of subsidence in the position of well 8*a*[3] without some subsidence also in the position of well 6, which seems to be on the salt table, though at or near its edge. But if there was subsidence in that position also, the difference in elevation between the top of the Jackson in well 6 and in well 8*a* can not be taken as giving the total amount of subsidence in the position of well 8*a*. Furthermore, if the uplift of the Jackson, which brought its top 200 feet above its normal regional position (see Lahee's Table II), occurred after deposition of the Oligocene, something should be added to the amount of subsidence estimated by Lahee in paragraph 6, page 282 of his paper, to allow for reduction of the difference in elevation

[1]The figure is not simply 10 per cent of 1,100 because lowering the top of the salt a specified amount involves raising the top of the cap by the assumed 10 per cent of anhydrite added to it. The process is, therefore, represented by a geometric progression expressed by the formula:

$S = \frac{a}{1-r}$ in which S = thickness of salt dissolved, in feet; a = amount of lowering of the overlying beds in feet; r = ratio of the thickness of anhydrite freed, to the thickness of salt dissolved.

[2]Levi S. Brown, "Cap-Rock Petrography," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 15, No. 5 (May, 1931), p. 517.

[3]F. H. Lahee, *op. cit.*, p. 282, paragraph 6.

between the center of the dome in well 8*a*, and the edge in well 6, by the relatively greater uplift—which would be the counterpart of the greater subsidence—in the center. The total indicated subsidence may therefore be considered greater than Lahee's minimum, though it can not be calculated from the data at hand.

As a matter of fact, subsidence in the central part of salt domes has long been recognized as one of their common characteristics—a characteristic, in fact, by which many have been discovered. It is only in degree that the Clay Creek and Chestnut domes are striking. That difference, however, suggests many problems. Indeed, to say that the presence of a solution surface on the top of salt domes is well established by the common occurrence of the relatively flat salt table and of anhydrite cap rock, is far from saying that that solution surface is explained. It may, in fact, be regarded as one of the unsolved problems about salt domes which has the greatest general geologic interest and significance. The solution of it would also probably be of much use in solving the general problem of oil-field waters. The opportunity is one that calls for recognition. This mass of soluble material, the salt core, thrust into the midst of beds of otherwise very simple structure and composition, is almost like a recording instrument placed there to furnish a record of water conditions, if we can find the key to the record.

The commonly recognized type of flow of water in depth below the water table is artesian. Artesian flow, as commonly understood, is flow of water that penetrates from the surface into a channel which comes to the surface again at some point far enough below the point of entry to permit the water entering it to escape.

The channel may be a single more permeable bed, it may be a more permeable bed and a fissure intersecting it, or it may be merely a set of intersecting fissures.

As might be expected from their mode of origin, many salt domes are associated with faults and there must be many such faults undiscovered. Perhaps most of the solution of the top of the salt can be accounted for by escape, along these faults, of water occurring in more permeable beds cut by the salt core. Yet it would seem as though solution in that way would produce irregular, unsymmetrical tops, very different from those that are commonly encountered. As most of the faults are probably near the periphery of the salt core, one would expect solution by water moving up these faults to bevel the top of the core rather than to cut it off flat and horizontally. The tangential relation between fault and salt surface illustrated in Figure 7 of Spooner's paper on the "Interior Salt Domes of Louisiana"[1] and in Figure 10 of Powers' paper on the "Interior Salt Domes of Texas,"[2] is rather what I would expect if solution were controlled by faults. It may well be, however, that faults, even if they can not produce flat salt tables, have been a factor in lowering the top of the salt core at some earlier stage.

It is not clear how the older beds of the Gulf Coastal Plain, buried as their gulfward ends seemingly must be under younger deposits, can, in the

[1]W. C. Spooner, *Geology of Salt Dome Oil Fields* (Amer. Assoc. Petrol. Geol., 1926), p. 280.

[2]Sidney Powers, *op. cit.*, p. 250.

absence of intersecting faults, have any natural circulation along them. But, if there is such circulation, intersection of one of the more permeable beds, by the salt core, would probably lead to the formation of a salt table at the level of the bed. As faulting has undoubtedly been common at times in the history of the Gulf Embayment, both around salt domes and between them, circulation along more permeable beds might be a factor in the production of salt tables.

But it is probable that artesian water escapes not only along definite channels, but that there is also a slow upward movement through the pores of the beds overlying the more readily permeable layers, as a result both of its hydrostatic head, and of the compaction of the sediments by the weight of rock overlying them. As the contact of the salt core and the cap rock would not, *per se*, be a water-bearing horizon and the salt would presumably not contain free water, water from adjacent beds would have to work its way into this contact, before upward percolation could be effective in forming a salt table, and it is difficult to conceive of a flat salt table resulting from this process unless the top of the salt core lay at the level of a more permeable water-bearing bed. But it is conceivable that an initially dome-shaped top might, by upward movement of water from some more permeable bed along the contact of salt core and surrounding sediments, be reduced to a flat top at the level of the more permeable bed, or the top might, in its upward progress, be arrested by intersecting some such bed.

Too little can be said about this possible type of underground circulation to justify further consideration. If it exists, it seems probable that in its rate of action and in its effects in transporting salt in solution into the surrounding sediments, it might be similar to diffusion, to be discussed more fully now.

The possibility that diffusion might carry salt from depth to overlying beds and therefore ultimately to the surface, has been recognized by both Richardson[1] and Fulda.[2]

To Fulda, who has considered the problem of the solution of the top of the salt core in relation to the salt table of German salt domes, it has seemed that diffusion alone might account for the formation of the salt table of the more deeply buried German salt domes in their present position. His main reason for seeking some such explanation seems to be that the German salt domes in question occur in plains country remote from any mountain mass that might serve as a source of artesian pressure, though he admits that saline springs actually have been typical in connection with many north German salt domes. It is not necessary to go into the explanation he offers to account for this seeming anomaly, as he himself considers it very hypothetical. If faults around salt domes can be assumed as outlets for artesian water, the necessary head for artesian flow would certainly seem to be available around our Gulf Coast salt domes, because the formations cut off by the flanks of the salt core, in most if not all of them, lie well below sea-level, therefore well below the inland outcrop of these formations, where artesian water would enter.

[1]G. B. Richardson, "Note on the Diffusion of Sodium Chloride in Appalachian Oil-Field Waters," *Jour. Washington Acad. Sci.*, Vol. 7 (1917), pp. 73-75.

[2]Ernst Fulda, "Salzauslaugung," *Jahrb. des Halleschen Verbandes für die Erforschung der mitteldeutschen Bodenschätze, et cetera*, Halle (Saale), Germany, Vol. 4, Liefg. 2 (1924), pp. 369-79.

However, for most of the deeper Gulf Coast salt domes there is no *a priori* reason for assuming peripheral faults coming to the surface. Surface doming above them, where it occurs at all, is generally slight, and in the absence of evidence to the contrary it must, therefore, be assumed that there has been little upward movement of the salt core since the surface beds were deposited, therefore little probability of faults reaching through to the surface. Neither are any shown in the volume *Geology of Salt Dome Oil Fields*. Salt springs have, however, I believe, been found in connection with some Gulf Coast salt domes, and a study of their occurrence and composition in relation to other features of the salt dome might help to clarify the problem under consideration.

The rates of solution determined by using the same formula as Fulda for diffusion, and assuming a solid column of water between the top of the salt core and the surface of the earth, conform well with assumptions about geologic time. But when allowance is made for the fact that the average cross section of water-bearing spaces is only a small percentage of the cross section of the column of rock above salt domes (15 per cent is probably a liberal estimate for the rocks of the Gulf Coast), the figures lose all significance.

Nevertheless, if we consider that there were perhaps 24,000,000 years available for the Oligocene-Miocene subsidence at Clay Creek, it is difficult, in spite of the pronounced faulting there, to believe that active circulation of water can be the cause for that subsidence. Moreover, it seems to me almost necessary to assume some uniform radial spread of salt in solution above salt domes to explain the very regular and symmetrical distribution of chlorine in the waters adjacent to salt domes, so strikingly brought out in Minor's paper on "Chemical Relations of Salt Dome Waters,"[1] less systematically and conclusively indicated by analyses published by Harbort,[2] and mentioned in more general terms by Fulda.[3]

Certainly this regular distribution, and especially the fact, mentioned by Minor, that chlorine decreases uniformly away from the salt *on the flanks* as well as above the dome, is strongly opposed to the assumption that the principal circulation of water is on faults around it or that there is, in fact, any active circulation. Perhaps the slow upward circulation through pores, already referred to, combined with diffusion, will be found, in the end, to account for the lowering of the tops of salt cores under present conditions. It does not seem, however, as though there were any way in which diffusion could produce a flat salt table. It might, if the salt core were at rest, perpetuate such a top, once it had been formed, but there seems to be no reason why it should not by itself produce a dome-shaped top. All considerations, therefore, lead to the conclusion that the flatness of the salt table is probably caused by a more permeable bed in the surrounding rocks. It should be noted, moreover, that whatever process of solution produces the salt table must act more rapidly than the flowage of the salt, which would presumably tend toward a dome-shaped top.

[1]H. E. Minor, *Geology of Salt Dome Oil Fields* (Amer. Assoc. Petrol. Geol., 1926), pp. 777-80.

[2]E. Harbort, "Salzgehalt der Nebengesteine an den norddeutschen Salzstöcken," *Zeits. der deutschen geol. Gesel.*, Vol. 65 (1913), Monatsber., pp. 108-12.

[3]Ernst Fulda, *op. cit.*, p. 377.

It is obvious that, to test the hypothesis of upward percolation or diffusion, it is desirable to analyze the water not only of the more permeable water-bearing sands, but also that contained in the pores of the less permeable intervening beds.[1]

Involved in the entire problem of salt-dome history is the question as to why the tops of different salt domes lie at different depths and whether they are fixed at those depths, or moving. Why, for example, has there been so little net movement at Clay Creek since Miocene time? Have solution and upward movement balanced each other, or has there been practically none of either? The latter condition would raise questions about diffusion and upward percolating waters as the cause of solution. It suggests the possibility of a depth below which solution does not occur at all. But it would also raise tectonic questions. Are we, in view of this, to assume that the movements of salt cores are due primarily to definite widespread orogenic movements, and that there has been no such movement in the Gulf Embayment since the beginning of the Oligocene? Or, if we believe in hydrostatic upward movement of the salt core as a result of the weight of overlying beds, why has there been no such movement as a result of the deposition of the Oligocene and Miocene in the region of the Clay Creek dome? Perhaps such domes, in which upward movement seems to have come to an end, may be regarded as "dead" domes in which the underlying salt bed, from which the salt core is presumably derived, has been completely squeezed out into the core. Or perhaps the top has been arrested at the intersection with some more permeable water-bearing bed.

Another factor which bears on the general problems related to the solution of the top of the salt core, and on which it would be very desirable to gather data, is the condition of the contact of salt and cap rock. In many places (on the Hockley salt dome, for example, as shown by the recently sunk shaft)[2] the salt and anhydrite are continuous or "frozen" to each other. On the Winnfield and Grand Saline salt domes, on the contrary, I understand[3] that there is water at the contact. In both these domes, however, the top of the salt is much nearer the surface than at Clay Creek; or than at Hockley, Bay St. Elaine, or Boling, from all of which I have specimens showing a "frozen" contact between salt and anhydrite. If one were to generalize from these few examples one would say that the presence of a layer of water between salt and anhydrite cap is related to depth, such free water occurring below the water table but being limited in depth by some other factor, perhaps the same factor as that which caused the rate of increase of salinity recorded by Minor,[4] to be uniform, apparently, only below the 2,000-foot level. It would be a valuable contribution to geology to determine what that factor is. As I see it, the presence of a layer of water at the contact of salt and anhydrite would not necessarily imply circulation and its absence would not preclude the possibility of diffusion by interstitial water, though it seems probable that the two conditions represent two very different present stages or processes.

[1] *Cf.* E. Harbort, *op. cit.*

[2] L. P. Teas, "Hockley Salt Shaft, Harris County, Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 15, No. 4 (April, 1931), pp. 465-69.

[3] Letters from Sidney Powers, February 24, 1931, and L. P. Teas, June 18, 1931.

[4] H. E. Minor, *op. cit.*, p. 778.

It is conceivable, however, that water might be absent at one part and not necessarily at another, perhaps a more fissured or permeable part.[1] But such a condition would probably work against flatness of the salt table unless fissuring, in the course of time, occurs everywhere on the contact. Perhaps the downward movement of the top of a salt core, at Clay Creek for example, is due above a certain level to actively circulating water and below that to diffusion and upward percolation.

The character of the salt at the contact is also a factor to be considered. As I recall it, all the cores I have seen, of salt from directly below the cap rock, are free from sedimentary banding, generally coarsely crystalline, and pure in appearance. I think there is no doubt that this is a *salt cap*, that is, a recrystallized part of the top of the salt core. Recrystallization, in many places with chemical change, is common at the top of the salt core of German salt domes. It seems probable that the presence or absence of such a salt cap might be significant as an indication of whether anhydrite cap-rock formation is or is not occurring at present, the presence of a salt cap indicating that anhydrite cap rock has not recently been forming or that it has been forming by some very slow process.

Finally, there is to be borne in mind, as a general consideration, the possibility of cycles in the history of salt domes of an area like that of the Gulf Embayment. If there are such general areal cycles, the present condition of the salt cores—their salt tables, their salt caps, their contacts between salt and cap rock, the distribution of salt in adjacent sediments—may illustrate only a phase of their history and may fail to account for all of that history or for many of their present characters.

SUMMARY AND CONCLUSIONS

In this discussion the purpose has been to indicate: that most, if not all, cap rock is evidence of very extensive solution of the top of the salt core on salt domes; that the net movement of the top of salt cores is the combined effect of upward flowage of the salt and downward solution of its top; that this may account for the stratigraphic evidence of complicated up-and-down movements above the salt core at Clay Creek; but that the movements indicated are far from adequate to account for the entire thickness of cap rock, which may, therefore, be accounted for either by a mutual cancellation of upward movement and solution or by solution, perhaps at the surface, before deposition of the beds (Wilcox) now resting directly on the cap rock.

The process of solution of the top of the salt core and the factors bearing on it have been discussed and it has been shown that it presents many problems. Consideration of several different processes has tended to indicate that a more permeable bed, among those penetrated by the salt core, is probably the cause of the relatively flat salt table, but that, in many cases, a slow uniform transfer of salt upward, either by percolation of water through pores of the overlying beds, or by diffusion, or by a combination of the two, is probably a factor in solution. It was suggested that faults may, however, be the determining factor

[1] I have since learned from L. P. Teas, June 18, 1931, that the water-bearing anhydrite sand at the contact of anhydrite cap rock and salt in the salt mine shaft on the Winnfield dome, was found only in a pocket 4 feet square. The water was under a pressure of 220 pounds per square inch.

in the solution of the tops of salt cores at certain stages, but that in the absence of faults, theoretical considerations and observed facts are opposed to the assumption of circulation of water along permeable beds as a cause of the solution of the salt cores. In general, these conclusions indicate the desirability, as one of the first steps in an attack on the problem, of gathering information about the position of more permeable beds ("water sands") in relation to the top of the salt core.

The possible significance of the character of the contact of anhydrite cap and salt, of the depth of the top of the salt core, and of the salt cap has been mentioned.

Finally, attention has been directed to the importance, for general geology as well as for the geology of salt domes, of the problems connected with the movements of the top of the salt core of salt domes, in the hope that those in a position to gather evidence toward the solution of these problems might be stimulated to do so.

MARCUS I. GOLDMAN

U. S. GEOLOGICAL SURVEY
May 13, 1931

CLAY CREEK SALT DOME, WASHINGTON COUNTY, TEXAS

There is great diversity of opinion about the method of origin of salt domes, the source of the salt, and the origin of the cap-rock anhydrite ordinarily associated with them. There are those who believe that the salt plug was intruded into the strata surrounding it long after these strata were deposited, and there are others who believe that the salt intrusion was accomplished almost *pari passu* with sedimentation. Some geologists argue strongly for the view that the anhydrite cap rock which occurs on some domes is what we may call a "biscuit," punched out from an original sedimentary stratum of anhydrite and thrust up on top of the salt; whereas other geologists contend that this anhydrite is a residual mass of insoluble material, formerly scattered through the salt, but left behind as the salt was gradually dissolved.

Whether we believe that the anhydrite cap is a "biscuit," or a residuum from solution of salt, we encounter serious difficulties which can not yet be explained away. For example, if it is assumed that the former hypothesis is correct, why are there not similar "biscuits" of sedimentary deposits other than anhydrite? Why, in the Gulf Coast area, are there no plugs overlain by caps of Eocene or Cretaceous sediments? If, however, we favor the residuum theory, how can we explain such features as the sandstone bands in the anhydrite cap rock, and especially a *straight* salt-anhydrite contact, like that found in the shaft at Hockley?[1] A contact produced by solution should be irregular and pockety, with embayments of the residual material (anhydrite) projecting downward into the original, unaltered material (salt), as seen in cross section.

Is it not possible that both modes of origin occurred in different degrees in different places? Must we assume these theories are strictly alternative? May not the processes have been coöperative in varying degrees?

[1] L. P. Teas, "Hockley Salt Shaft, Harris County, Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 15, No. 4 (April, 1931), pp. 465-69.

As shown by Dr. Goldman in the foregoing discussion, there are many features which strongly suggest the residuum mode of origin of the anhydrite cap. Let us consider a little further the conditions at Clay Creek.

Let us assume that a salt plug, in its earlier stages of growth, has a conical or dome-shaped top. On the residuum theory of anhydrite cap-rock origin, the process of solution would almost certainly be concentrated at the peak, with a tendency at first to flatten the cone or the dome. Here, very probably, during the rise of the plug, would be encountered the least saline waters, those most capable of taking salt into solution. But would not the gradual expansion and thickening of the anhydrite cap serve to retard the solution beneath the cap, and thereby relatively increase the rate of solution where the salt was still uncovered or only thinly covered, thus tending to *preserve* the conical or rounded top of the plug instead of developing the flattened "salt table?" It was this idea that led me to write the passage, no doubt too brief and too obscure, quoted by Dr. Goldman, as follows: "The fact that a maximum thickness of cap rock has been found in the central basin does not seem to justify the theory of solution of the salt as a cause of the down-sinking."

The top of the salt in well 8*a*, near the center of the Clay Creek dome (see Figure 1, herewith; also Figure 1, p. 280, Vol. 15, this *Bulletin*), is 2,933 feet below sea-level; in well 6 (same figures) it is 2,855 feet below sea-level; and in Clay 4 (Fig. 1), the top of the salt was reached at 2,970 feet, after penetrating 270 feet of anhydrite. Clay 4 was drilled about as far east of Freeman 1 (well 8*a*), as well 6 was drilled southeast of 8*a*. These three wells seem to have reached the salt at almost the same level, the "salt table." Southwest of well 8*a*, twice as far from 8*a* as 6 is distant from 8*a*, Janner 4 penetrated anhydrite from −2,865 to −3,545 and salt from −3,545 to −5,320 feet. Observe that a thickness of 680 feet of anhydrite was penetrated here, several hundred feet below the "salt table." As far as we can determine from the few wells drilled to salt, this "table" seems to be closely related in areal extent with the central basin (see pp. 48, 51, and 279, Vol. 15, this *Bulletin*) because, outside the rim, the salt-anhydrite contact seems to dip radially outward almost parallel with the overlying tilted sediments. It is interesting to note further that cores of salt show definite "annual layers" which also have dips approximating, in amount, those of the overlying strata; but the *direction* of dip of these annual layers was not ascertained. There is a strong supposition that they were inclined with the dip of the strata.

The stratigraphy at Clay Creek indicates that, from middle or upper Wilcox time to the end of Jackson time, the dome as a whole was rising almost as fast as the sediments were accumulating; therefore, almost *pari passu* with regional settling of this part of the Gulf Coast embayment. There is no reason to believe that this series of formations, outward from the rim of the central basin, was lifted much above its present position by intrusion of the salt, and subsequently was lowered to its present position by the sinking of the top of the salt through solution. In other words, from the basin rim (well 3, Fig. 1, p. 280) outward we may assume that there has been little if any subsidence. Therefore, in this outer annular region the anhydrite cap was either brought up with the salt, or was formed by solution of the underlying salt at a rate slightly slower that the uplift of the plug as a whole. Such a balance of rates of solution of

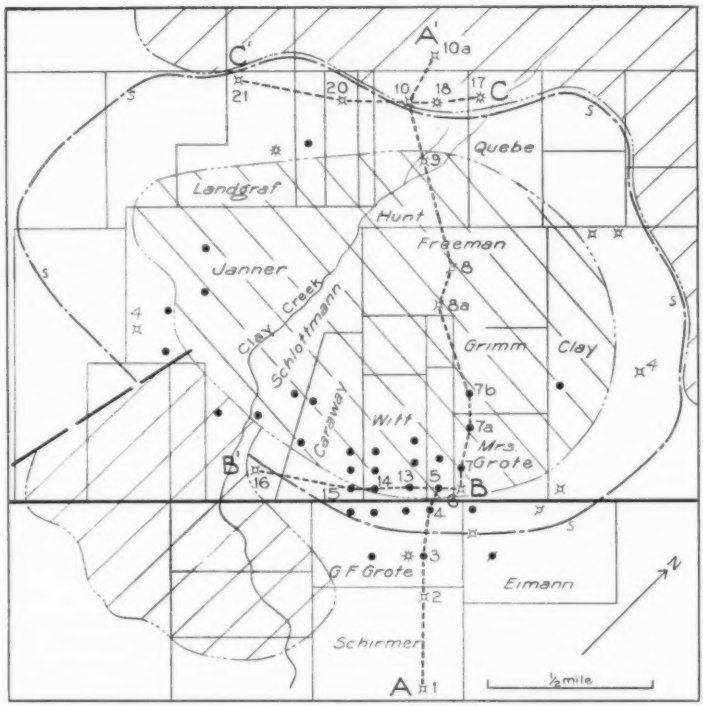


FIG. 1.—Outline map of surface geology of Clay Creek dome, Washington County, Texas, showing positions of sections *AA'*, *BB'*, and *CC'*, as illustrated on pp. 50, 52, 53, and 280, of Vol. 15 of this *Bulletin*. Additional wells are represented. Compare Figure 3, p. 47 of this volume. E.-W. ruling, Oakville; blank, Catahoula; N.-S. ruling, Jackson. Within dot-and-dash line (*SSS*), Catahoula dips inward toward Oakville; outside this line, dips are outward.

salt, upthrust of salt, deposition of sediments, and settling of the region as a whole, is indeed remarkable, although quite possible.

Within the rim at Clay Creek, undoubtedly settling of the formations from upper Wilcox to upper Jackson has occurred since the time of their accumulation in a relatively higher position; and Oligocene and probably lower Miocene formations were accumulating during this period of settling. If we take an average of 600 feet for the thickness of the anhydrite cap prior to the settling of the central basin,[1] this leaves approximately another 600 feet for the maximum thickness of anhydrite in the middle of the central basin (well 8*a* had 1,187 feet), a thickness which we may attribute, on the solution theory, to the dis-

[1]Approximately the average thickness of anhydrite on the rim and down the outer flank of the dome.

solving of salt while the central subsidence was in progress. Analyses of salt from several cores on this dome have shown an average content, by volume, of approximately 6 per cent anhydrite in the shape of grains or crystals of this substance scattered in layers in the salt (the "annual layers"). On this basis, a thickness of 600 feet of anhydrite cap would require the solution of a vertical thickness of 11,650 feet of salt. Dr. Goldman assumes an average anhydrite content in the salt of 10 per cent, and states that this is probably high (p. 1106). He estimates that in this case a column of salt 1,100 feet high would account for approximately 120 feet of the anhydrite in well 8*a*. The problem, as I see it, is not in finding enough salt theoretically to yield the measured thickness of anhydrite, but to show through what agencies and under what conditions, of depth, structure, et cetera, this enormous bulk of salt was removed, seemingly *pari passu* with its uplift, its upper surface being maintained within comparatively narrow limits of depth.

From the cores secured at Clay Creek, there is indication of a reduction in the amount of anhydrite in the salt at increasing depths (note that Janner 4 penetrated 1,775 feet of salt). Conversely, we might infer, if we accept the solution theory, that the salt dissolved to form the cap may have contained more than an average of 6 per cent anhydrite; consequently, that less salt may have been required to build up 600 feet of anhydrite.

In regard to a "salt cap," mentioned by Dr. Goldman (p. 1112), we discovered no such layer of recrystallized salt. If there is any such, it can be only a very few feet thick.

The fact that the salt plug ends upward in a nearly flat table certainly suggests a definite "base-level" of solution; but what could this "base-level" have been? Dipping steeply against the plug, and in part arching over it, is the Wilcox formation (Fig. 1, p. 280), which, on the rim of the dome, has been raised above its normal position approximately 2,000 feet. Previous to the central subsidence, it formed a great dome over the plug. Within this dome circulation of Wilcox water would have been practically nil, unless such water had upward egress through faults intersecting the dome. Even in this event, these waters would probably have had a fairly high saline content; furthermore, as mentioned by Dr. Goldman, such fault egress would not explain the localization of the "table." I want particularly to emphasize this fact of the arching of strata above the dome, as this relation seems greatly to increase the difficulty of determining the condition which localized the solution and tended to level the "table." Another difficulty here is the fact that the anhydrite cap hangs far over the sides of the salt, to depths far below the level of the "table," in such a way that seemingly it would have prevented the functioning of any outside control.

The object of the foregoing remarks is mainly to add more information, and especially to join Dr. Goldman in encouraging more careful study of the known facts, collection of more data along certain indicated lines, and concentration of thought on some of the more difficult phases of the problem.

FREDERIC H. LAHEE

DALLAS, TEXAS
June 23, 1931

REVIEWS AND NEW PUBLICATIONS

"Physics of the Earth—II. The Figure of the Earth." *National Research Council Bull. 78* (February, 1931). National Academy of Sciences, Washington, D. C. 286 pp., 46 figs. 9¾ × 7 inches.

This volume is one of several which are to be published by the National Research Council on various phases of geophysics. The book is illustrated and has excellent bibliographies on each subject. Short historical sketches of the development of each of the main topics add considerably to the reader's interest.

The book contains three main topics: (1) Tides, Ocean and Earth; (2) Gravity, Deflection of the Vertical, and Isostasy; and (3) Variation of Latitude. There are several chapters in each of these divisions. The following well known men,—G. T. Rude, A. T. Doodson, Paul Schureman, H. A. Marmer, William Bowie, Harry Fielding Reid, C. H. Swick, Donald C. Barton, D. L. Parkhurst, H. G. Avers, C. V. Hodgson, and W. D. Lambert,—contributed chapters.

In the first section is a discussion of the relation of the main tides to the position of the sun, moon, and earth; a description of instruments for tidal measurement; and a somewhat meager outline of both the non-harmonic and harmonic methods of analysis showing how tidal data are utilized.

The section on isostasy points out the fundamental reasoning on which the theory is based. The original paper, by C. E. Dutton, introducing the word isostasy, is reproduced. Dutton showed that the contractional hypothesis is of little value because the amount of contraction is too small and the forces are nondirectional, and it does not explain large folds, such as the Appalachian system. He regards isostasy, with the horizontal flowing of materials, as the cause of these plications.

There are two main methods of making gravity observations, by pendulum and by torsion balance. The former and the apparatus used are described in detail, together with the development leading up to the more recent submarine gravity measurements, but no mention is made of the most recent developments of the pendulum in petroleum exploration work where, by radio beating, the accuracy is claimed to have been considerably increased.

The torsion balance method is described by Barton.

Both the astronomical and geodetic determinations of geographic position are treated in considerable detail by Hodgson.

Various methods of base-line measurements are described.

In the third section, it is shown that variations in latitude may be produced either by changes in direction of the vertical or by changes in the direction of the earth's axis. As the former of these is ordinarily negligible, the chapter is devoted chiefly to the latter variation.

B. B. WEATHERBY

TULSA, OKLAHOMA
June 29, 1931

RECENT PUBLICATIONS

COLORADO

Tentative Correlation of the Named Geologic Units of Colorado, compiled by M. Grace Wilmarth, secretary of Committee on Geologic Names (U. S. Geol. Survey, Washington, D. C., June, 1931). 3 charts, 29¼ × 3¼ inches.

FLORIDA

"Petroleum Possibilities." *Florida State Geol. Survey 21st-22d Ann. Rept.* (Tallahassee, 1931). Postage, $0.03.

GENERAL

Principles of Structural Geology, by Charles Merrick Nevin. (John Wiley and Sons, Inc., New York, 1931). 303 pp., 126 figs. 6 × 9 inches. Cloth. Price, $3.50.

"Report of the Committee on Sedimentation, 1929-1930," *National Research Council Reprint and Circular Series No. 9* (1931). Prepared under auspices of Division of Geology and Geography, National Academy of Sciences. Washington, D. C. 97 pp. 6¾ × 9¾ inches. Price, $1.00.

KENTUCKY

"Oil and Gas in Western Kentucky," by W. R. Jillson. *Kentucky Geol. Survey* (Frankfort), Ser. 6, Vol. 39 (1930). 632 pp., 45 photographs, maps, and diagrams. Cloth, 6 × 9 inches.

OKLAHOMA

Tentative Correlation of Sands and Limes Encountered in Oil and Gas Wells in Oklahoma, compiled by M. Grace Wilmarth, secretary of Committee on Geologic Names (U. S. Geol. Survey, Washington, D. C., February, 1931). Chart, 26 × 24 inches.

TEXAS

Oil and Gas Fields of the State of Texas (U. S. Geol. Survey, Washington, D. C., June, 1931). Map; scale, 1:750,000. Price, $0.50.

UTAH

"The Wasatch Plateau Coal Field, Utah," by E. M. Spieker. *U. S. Geol. Survey Bull. 819* (Supt. Documents, Washington, D. C., June, 1931). 210 pp., 33 pls. (including 3 maps), 11 figs. Price, $1.30.

WEST VIRGINIA

The West Virginia Geological Survey, at Morgantown, announces the following:

Bituminous Coal Beds in West Virginia. Drafted figure, size 6½ × 37 inches. Price, $0.25.

Randolph County Report. Ready November 1, 1931. Price, $3.00.

State Geologic Map. Ready January 1, 1932. Orders taken now. Price, $1.00.

THE ASSOCIATION ROUND TABLE

SUPPLEMENTARY MEMBERSHIP LIST, SEPTEMBER 1, 1931

Members	48
‖Associates	59
Total additions since publication of list in March *Bulletin*	107

Adams, Lowell A., 324 S. Rampart Blvd., Los Angeles, Calif.
Alexander, Alex M., 704 Masonic Bldg., Bartlesville, Okla.
‖Anderson, Richard S., Box 2022, Tulsa, Okla.
‖Bailey, Donald G., 1221 Subway Terminal Bldg., Los Angeles, Calif.
Bailey, J. P., N. V. Ned. Pac. Petr. Mij., hoek Stradhuisplein, Batavia, Java, D. E. I.
‖Barksdale, J. D., 133 W. Gray St., Elmira, N. Y.
‖Barnes, Virgil E., 591 Ohio Ave., Chahalis, Wash.
Barrow, Geoffrey, 344 Robin Hood Lane, Hall Green, Birmingham, England.
‖Bayle, Pierre, Caribbean Petr. Co., Maracaibo, Venezuela, S. A.
Beers, Roland F., 1311 Republic Bank Bldg., Dallas, Tex.
Belluigi, Arnaldo, Via. Vitt. Em. 178, Parma, Italy.
‖Benson, Don G., Box 263, Tulsa, Okla.
‖Benson, Edmund T., State Geological Survey, Urbana, Ill.
‖Boehms, E. F., 214 S. Madison St., San Angelo, Tex.
‖Boyle, Huron L., McGregor, Iowa.
‖Boyles, James M., 2006 Gulf Bldg., Houston, Tex.
Brown, Levi S., University Station, Austin, Tex.
Bush, Frederic A., 1404 S. Norfolk, Tulsa, Okla.
‖Cadman, A. Denys, 32 Westhill, Highgate, London, N. 6, England.
‖Clark, G. Conrad, Megargel, Tex.
‖Craig, T. C., Phillips Petroleum Co., Amarillo, Tex.
‖Dietert, Arthur E., Box 91, Cuero, Tex.
‖Drake, Lemuel Clyde, Box 1024, Memphis, Tenn.
‖Dunn, Jack W., 407 Herald Bldg., Calgary, Alta., Canada.
‖Evans, Vincent, Hugo, Okla.
Fisher, Leslie A., Box 908, Tyler, Tex.
‖Fly, Paul J., 715 W. Pine St., Hattiesburg, Miss.
Foran, William T., Maries, Idaho.
Fossa-Mancini, Enrico, Direccion General Y. P. F., Buenos Aires, Argentina, S. A.
‖Garst, Jarvis, Apartado 209, Monterrey, N. L., Mexico.
Goodman, P. W., Box 971, Oklahoma City, Okla.
‖Goodwill, Donald, Jr., 503 E. & W. St., Minden, La.
Gow, Kenneth L., 924 Subway Terminal Bldg., Los Angeles, Calif.
Greenwood, Chester L., 3905 Clayton Ave., Los Angeles, Calif.
‖Guerrero, Alberto L., Apartado 285, Tampico, Mexico.
Gutenberg, Beno, Seismological Laboratory, 220 N. San Rafael Ave., Pasadena, Calif.
‖Haas, Johann Otto, Noumea, New Caledonia.
‖Hagan, Cecil Vernon, Gonzales, Tex.
Hancock, J. M., Geol. Dept., United Production Corp., Beeville, Tex.
Harrison, John Vernon, 34 Rowallan Gardens, Glasgow, W. 1, Scotland.
‖Hatfield, Arlo C., Drawer C., Borger, Tex.
Helquist, G. A., Luteranskiy per N. 3, No. 3, Baku, U. S. S. R.
‖Hemphill, Herbert A., 2 N. Bishop St., San Angelo, Tex.
Henbest, Lloyd G., 14 Glendale Road, Sharon, Mass.
Heusser, Hans, Caribbean Petr. Co., Maracaibo, Venezuela, S. A.

‖Associate.

||Hicks, Ira M., Box 731, Tyler, Tex.
||Houston, Sam H., Jr., 2015 Smith-Young Tower, San Antonio, Tex.
Johnson, Carlyle D., 401 Continental Oil Bldg., Denver, Colo.
||Jones, Stephen Barr, 505 Herald Bldg., Calgary, Alta., Canada.
Karcher, John C., 3303 Mockingbird Lane, Dallas, Tex.
Kihlstedt, Folke H., 26 Beaver St., 12th Floor, New York, N. Y.
||Kirby, Louie C., Box 505, Longview, Tex.
Kitchin, Walter, Iraq Petroleum Co., Ltd., Kirkuk, Iraq.
||Knight, J. Brookes, Peabody Museum, Yale University, New Haven, Conn.
Laughbaum, Graydon H., Sinclair Oil & Gas Co., Box 2026, Tulsa, Okla.
||Leach, Walter W., Groesbeck, Tex.
Lees, George M., Anglo-Persian Oil Co., Ltd., London, E. C. 2, England.
Littlefield, Max S., Box 2044, Tulsa, Okla.
||Logie, Russell M., Peabody Museum, Yale University, New Haven, Conn.
||Lokman, Kemal, Mevsom Sokak No. 6, Ankara, Turkey.
Lovering, T. S., U. S. Geological Survey, Golden, Colo.
||Marie, Marcel, c/o Ottoman Bank, Mosul, Iraq.
McClure, J. H., Prairie Oil & Gas Co., Midland, Tex.
||McGee, Mary Kathryn, The Texas Co., 929 S. Broadway, Los Angeles, Calif.
Mellen, William P., 4846 Tennyson St., Denver, Colo.
|| Miller, William C., 1455 Marlboro Ave., Wilkinsburg, Pa.
Miller, William Dana, Apartado 478, Caracas, Venezuela, S. A.
Milner, Henry Brewer, 92 Victoria St., Westminster, London, S. W. 1, England.
||Monroe, Watson H., U. S. Geological Survey, Washington, D. C.
||Montgomery, Phil C., Box 387, Chickasha, Okla.
||Moore, Barton W., 315 N. Fredonia St., Longview, Tex.
Morgan, Ben F., 1109 Nixon Bldg., Corpus Christi, Tex.
||Morgan, Charles Gill, 4608 Abbott Ave., Dallas, Tex.
Neumann, Fred R., 6261 Hyacinth St., Chicago, Ill.
||Newell, W. John, United Gas System, Geol. Dept., Mason Bldg., Houston, Tex.
||Newland, John B., 308 W. Fifth St., Roswell, N. Mexico.
Pressler, Edward D., Humble Oil & Rfg. Co., Uvalde, Tex.
||Rhodes, Edward J., 6039 Hollywood Blvd., Los Angeles, Calif.
Ribble, John M., Fort Scott and Main Sts., Butler, Mo.
Rosaire, Carol G., 2110 Esperson Bldg., Houston, Tex.
Rosaire, E. E., 1407 Richmond Road, Houston, Tex.
||Schillhahn, E. O., 800 Union Trust Bldg., Springfield, Ohio.
||Schmotzer, J. W., 112 E. Jordon St., Shreveport, La.
||Schon, Otto, Baba-Gurgur, Kirkuk, Iraq.
Schürmann, H. M. E., van voorschotenlaan 2, The Hague, Holland.
||Simonton, Owen W., Room 12, Quinby Bldg., Wooster, Ohio.
Smalley, Claire F., 1512 S. Ninth St., Chickasha, Okla.
Smith, Arthur E., Box 1865, Houston, Tex.
Smith, James Edward, 150, Broomhill Road, Aberdeen, Scotland.
||Smith, Lee C., Box 100, Tyler, Tex.
Sorenson, I. L., Humble Oil & Rfg. Co., Kilgore, Tex.
||Stamey, Roderick A., Mt. Belvieu, Tex.
||Taegel, Edwin A., Continental Oil Co., Apartado 209, Monterrey, N. L., Mexico.
||Tarragona, José, Y. P. F., Division Geologia, Beunos Aires, Argentina, S. A.
||Teagle, John, Humble Oil & Rfg. Co., Roswell, N. Mexico.
||Thacher, John H., Jr., 1114 Standard Oil Bldg., San Francisco, Calif.
Tolwinski, Konstanty, Stacja Geologiczna, Boryslaw, Poland.
||Vallat, Eugene H., 505 Georgina Ave., Santa Monica, Calif.
Wantland, Dart, 600 Fourteenth St., Golden, Colo.
||Warner, Ralph E., Y. M. C. A., Bradford, Pa.
||Weidmann, Carl, Am Zweihonnschaftenwald 9, Essen-Bredeney, Germany.
||Westcot, Frank S., Box 464, Bayton, Tex.
||Winkler, Bruno Oscar, 208 Humble Bldg., Houston, Tex.
Winn, W. E., 3240 Daniel St., Dallas, Tex.
||Woods, Percy O., Humphreys Corp., Mt. Belview, Tex.
Zimmerman, C. C., Drawer F, Houston, Tex.
Zuber, Stanislav, Dlugosza 31, Lwow, Poland.

AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

WILLIAM A. WALDSCHMIDT, for the past 7 years geologist and subsurface laboratory technician with the Midwest Refining Company, Denver, Colorado, has opened a laboratory at 834 First National Bank Building, Denver, Colorado, and is equipped to do microscopic examination and correlation of oil well and outcrop samples, porosity determinations, mineral determinations, heavy mineral separations and microphotography.

R. A. F. PENROSE, JR., widely known geologist, died at Philadelphia, Pennsylvania, July 31, aged 67 years.

R. B. WHITEHEAD, chief geologist of the Atlantic Oil Producing Company, Dallas, addressed the first meeting of the East Texas chapter of the American Petroleum Institute, at Longview, Texas, July 15. He referred to the need and availability of geological advice to prevent salt water hazards in drilling and producing. The speech was reported in *The Oil Weekly* of July 24.

The Journal of Sedimentary Petrology, Vol. 1, No. 1 (April, 1931) was published last May. It is a semi-annual publication of the Society of Economic Paleontologists and Mineralogists, a technical division of this Association. The board of editors is composed of RAYMOND C. MOORE, P. G. H. BOSWORTH, MARCUS A. HANNA, HENRY B. MILNER, CLARENCE S. ROSS, RALPH D. REED, ARTHUR C. TROWBRIDGE, and W. H. TWENHOFEL. The subscription price is $3.00 per year. Address GAYLE SCOTT, secretary-treasurer, Texas Christian University, Fort Worth, Texas.

Mr. and Mrs. C. N. VALERIUS announce the birth of a son, John Behner, on June 13, 1931. Mr. Valerius is connected with the M. M. Valerius Royalty Corporation at Tulsa.

JOSEPH E. MORERO is in charge of the West Texas district offices of the Skelly Oil Company at Midland. His address is Box 1485. These offices were recently moved from San Angelo.

E. C. REED has severed his connection with the Lago Petroleum Corporation, Maracaibo, Venezuela, where he has been employed for the past 5½ years. His home address is 1316 South Twenty-fourth Street, Lincoln, Nebraska.

J. G. DOUGLAS, paleontologist for the Lago Petroleum Corporation, Maracaibo, Venezuela, for the past 3 years, has returned to his home, 3043 St. Paul Street, Baltimore, Maryland.

C. M. CREBBS, general agent for the Venezuela Gulf Oil Company, Maracaibo, is spending the summer in the United States. He left Maracaibo via

the Pan American Airway plane to Barranquilla, Kingston, and Miami, a route which has proved to be of great service to those in Venezuela.

G. MOSES KNEBEL, chief geologist for the Standard Oil Company of Venezuela (formerly Creole Petroleum Corporation) has been transferred to Maturin, eastern Venezuela, in connection with the general move of the Standard's offices from Maracaibo to Caripito, State of Monagas.

V. W. VANDIVER, in charge of the land department for the Standard Oil Company of Venezuela, has left Maracaibo for Caripito, where he will be stationed at the Standard's main offices.

L. W. HENRY, chief geologist for the Richmond Petroleum Company, (Standard of California) has returned to Maracaibo from a 3-months vacation spent in California.

J. M. DOUGLAS, manager of the Union National Petroleum Company, is now located in Caracas. The Union National recently closed their Maracaibo office.

CARL WIEDENMAYER, of the Standard Oil Company of Venezuela, is responsible for the location of the Standard's new wildcat well, Cumarebo No. 1, State of Falcon, which was recently completed, producing 700 barrels of oil through a ½ inch choke, 47.0° A. P. I., at 627 feet.

D. B. WILLIAMS, formerly chief scout for the Caribbean Petroleum Company, with headquarters in Maracaibo, has returned to his home in Wales. He may be reached at 179 Cathedral Road, Cardiff, Wales, Great Britain.

FLOYD HODSON and HELEN K. HODSON, of the Standard Oil Company of Venezuela, are spending their vacation in the United States. On their return they will be located at the Standard's new offices at Caripito, State of Monagas, eastern Venezuela.

PARKER D. TRASK is working for the U. S. Geological Survey, Washington, D. C.

P. L. KELLER, formerly of San Angelo, Texas, is now at 3508 Oakmont Avenue, Philadelphia, Pennsylvania.

LYMAN C. REED, formerly with the Standard Oil Company of New Jersey in Argentina and Bolivia, has recently returned to the United States. He may be addressed at Bryan, Texas.

EMIL OTT, formerly of San Angelo, Texas, is now at 26 Gutenbergstr., Bern, Switzerland.

PROFESSIONAL DIRECTORY

SPACE FOR PROFESSIONAL CARDS IS RESERVED FOR MEMBERS OF THE ASSOCIATION. FOR RATES, APPLY TO THE BUSINESS MANAGER, BOX 1852, TULSA, OKLAHOMA

CHESTER W. WASHBURNE
GEOLOGIST
149 BROADWAY NEW YORK

HUNTLEY & HUNTLEY
PETROLEUM GEOLOGISTS AND ENGINEERS
L. G. HUNTLEY
WILLIAM J. MILLARD
J. R. WYLIE, JR.
GRANT BUILDING, PITTSBURGH, PA.

EDWIN B. HOPKINS
CONSULTING GEOLOGIST
25 BROADWAY NEW YORK

GEO. C. MATSON
GEOLOGIST
PHILCADE BUILDING TULSA, OKLA.

G. JEFFREYS
CONSULTING GEOLOGIST
PHONE JOHN 2584
80 MAIDEN LANE NEW YORK

DABNEY E. PETTY
CHIEF GEOLOGIST
PETTY GEOPHYSICAL ENGINEERING COMPANY
SAN ANTONIO, TEXAS

J. P. SCHUMACHER W. G. SAVILLE
R. Y. PAGAN A. C. PAGAN
TORSION BALANCE EXPLORATION CO.
TORSION BALANCE SURVEYS
PHONE: PRESTON 7315
730-32 POST DISPATCH BUILDING
HOUSTON TEXAS

FREDERICK G. CLAPP
CONSULTING GEOLOGIST
50 CHURCH STREET
NEW YORK

F. B. PORTER, PRESIDENT R. H. FASH, VICE-PRESIDENT
THE FORT WORTH LABORATORIES
ANALYSES OF BRINES, GAS, MINERALS, OIL. INTERPRETATION OF WATER ANALYSES. FIELD GAS TESTING.
828½ MONROE STREET FORT WORTH, TEXAS
LONG DISTANCE 138

WILLARD W. CUTLER, JR.
EVALUATIONS AND GEOLOGICAL REPORTS
1844 BRONSON AVENUE
LOS ANGELES, CALIFORNIA

E. DeGOLYER
GEOLOGIST
65 BROADWAY NEW YORK

DONALD C. BARTON
GEOLOGIST AND GEOPHYSICIST
SPECIALIST ON
GULF COAST SALT-DOME AREA
EÖTVÖS TORSION BALANCE IN
DOMESTIC OR FOREIGN WORK
PETROLEUM BUILDING
HOUSTON TEXAS

PHILLIP MAVERICK
PETROLEUM GEOLOGIST
WESTERN RESERVE LIFE BLDG.
SAN ANGELO TEXAS

JOHN L. RICH
GEOLOGIST
OTTAWA KANSAS

KARL ETIENNE YOUNG
CONSULTING GEOLOGIST AND PALEONTOLOGIST
SPECIALIZING IN TERTIARY OF GULF COAST
EVALUATION OF SALT DOME OIL FIELDS
327 MASON BLDG. HOUSTON, TEXAS

BROKAW, DIXON, GARNER & McKEE
GEOLOGISTS ENGINEERS
OIL—NATURAL GAS
EXAMINATIONS, REPORTS, APPRAISALS
ESTIMATES OF RESERVES
120 BROADWAY NEW YORK

JOHN HOWARD SAMUELL
CONSULTING GEOLOGIST AND
PETROLEUM ENGINEER
1025-28 NEW MAJESTIC BUILDING
SAN ANTONIO, TEXAS
FIELD HEADQUARTERS
COLEMAN, TEXAS

CARROLL H. WEGEMANN
CHIEF GEOLOGIST
PAN-AMERICAN PETROLEUM AND
TRANSPORT COMPANY
122 EAST 42ND STREET
NEW YORK

R. W. LAUGHLIN L. D. SIMMONS
WELL ELEVATIONS
OKLAHOMA, KANSAS, TEXAS PAN-
HANDLE, AND EAST TEXAS
LAUGHLIN-SIMMONS & CO.
605 OKLAHOMA GAS BUILDING
TULSA OKLAHOMA

FREDERICK W. GARNJOST
SPUYTEN DUYVIL
NEW YORK CITY

ALEXANDER DEUSSEN
CONSULTING GEOLOGIST
SPECIALIST, GULF COAST SALT DOMES
1606 POST DISPATCH BUILDING
HOUSTON, TEXAS

FRED H. KAY
PAN-AMERICAN PETROLEUM AND
TRANSPORT COMPANY
122 E. 42ND STREET NEW YORK

Please use coupon on last page of advertisements in answering advertisers

PAUL P. GOUDKOFF
GEOLOGIST
GEOLOGIC CORRELATION BY FORAMINIFERA AND MINERAL GRAINS
1204 SUBWAY TERMINAL BUILDING
LOS ANGELES, CALIFORNIA

LEON J. PEPPERBERG
CONSULTING GEOLOGIST
COLUMBIA ENGINEERING AND MANAGEMENT CORP.
(COLUMBIA GAS AND ELECTRIC CORP.)
61 BROADWAY, NEW YORK
99 NORTH FRONT STREET, COLUMBUS, OHIO

J. S. HUDNALL G. W. PIRTLE
HUDNALL & PIRTLE
GEOLOGISTS
641 MILAM BUILDING SAN ANTONIO, TEXAS

WALTER STALDER
PETROLEUM GEOLOGIST
925 CROCKER BUILDING
SAN FRANCISCO, CALIFORNIA

DIRECTORY OF GEOLOGICAL SOCIETIES

FOR THE INFORMATION OF GEOLOGISTS VISITING LOCAL GROUPS. FOR SPACE, APPLY TO THE BUSINESS MANAGER, BOX 1852, TULSA, OKLAHOMA

PANHANDLE GEOLOGICAL SOCIETY

AMARILLO, TEXAS

PRESIDENT - - - - J. D. THOMPSON, JR.
ROOM 3, AMARILLO NATIONAL BANK BUILDING

FIRST VICE-PRESIDENT - - H. T. MORLEY
STANOLIND OIL AND GAS COMPANY

SECOND VICE-PRESIDENT - - J. V. TERRILL
GULF PRODUCTION COMPANY

SECRETARY-TREASURER - - A. R. KAUTZ
EMPIRE GAS AND FUEL COMPANY

MEETINGS: FIRST AND THIRD THURSDAY NOONS, EACH MONTH. PLACE: ROSE BOWL TEA ROOM.

NORTH TEXAS GEOLOGICAL SOCIETY

WICHITA FALLS, TEXAS

PRESIDENT - - - - WILLIAM J. NOLTE
DIXIE OIL COMPANY

VICE-PRESIDENT - - - - H. F. SMILEY
DEEP OIL DEVELOPMENT COMPANY

SECRETARY-TREASURER - VIRGIL PETTIGREW
HUMBLE OIL AND REFINING COMPANY

MEETINGS: SECOND FRIDAY, EACH MONTH, AT 6:30 P. M.
LUNCHEONS: FOURTH FRIDAY, EACH MONTH, AT 12:15 P.M.
PLACE: WICHITA CLUB, NATIONAL BUILDING

TULSA GEOLOGICAL SOCIETY

TULSA, OKLAHOMA

PRESIDENT - - - - - R. S. KNAPPEN
GYPSY OIL COMPANY

1ST VICE-PRESIDENT - - - - F. A. BUSH
SINCLAIR OIL AND GAS COMPANY

2ND VICE-PRESIDENT - - - C. L. SEVERY
816 KENNEDY BUILDING

SECRETARY-TREASURER - RONALD J. CULLEN
TWIN STATE OIL COMPANY

MEETINGS: FIRST AND THIRD MONDAYS, EACH MONTH, FROM OCTOBER TO MAY, INCLUSIVE, AT 8:00 P. M., FOURTH FLOOR, TULSA BUILDING. LUNCHEONS: EVERY THURSDAY, FOURTH FLOOR, TULSA BUILDING.

KANSAS GEOLOGICAL SOCIETY

WICHITA, KANSAS

PRESIDENT - - - WALTER W. LARSH
STANOLIND OIL AND GAS COMPANY

VICE-PRESIDENT - - EVERETT A. WYMAN
AMERADA PETROLEUM CORPORATION

SECRETARY-TREASURER - PAUL A. WHITNEY
MID-CONTINENT PETROLEUM CORPORATION

REGULAR MEETINGS, 12:30 P. M., AT INNES TEA ROOM, THE FIRST SATURDAY OF EACH MONTH. VISITING GEOLOGISTS ARE WELCOME.

THE KANSAS GEOLOGICAL SOCIETY SPONSORS THE WELL LOG BUREAU WHICH IS LOCATED AT 412 UNION NATIONAL BANK BUILDING.

THE SHREVEPORT GEOLOGICAL SOCIETY

SHREVEPORT, LOUISIANA

PRESIDENT - - - - S. C. STATHERS
STANDARD OIL COMPANY
BOX 1739

VICE-PRESIDENT - - - - C. L. MOODY
OHIO OIL COMPANY
GIDDENS-LANE BUILDING

SECRETARY-TREASURER - G. W. SCHNEIDER
THE TEXAS COMPANY
BOX 1737

MEETS THE FIRST FRIDAY OF EVERY MONTH, ROOM 605 SLATTERY BUILDING. LUNCHEON EVERY MONDAY NOON, WASHINGTON HOTEL.

HOUSTON GEOLOGICAL SOCIETY

HOUSTON, TEXAS

PRESIDENT - - - - J. BRIAN EBY
BOX 962

VICE-PRESIDENT - ALVA CHRISTINE ELLISOR
HUMBLE OIL AND REFINING COMPANY

SECRETARY-TREASURER - JOHN F. WEINZIERL
PETROLEUM BUILDING

REGULAR MEETINGS, EVERY TUESDAY AT NOON (12:15) AT THE UNIVERSITY CLUB. FREQUENT SPECIAL MEETINGS CALLED BY THE EXECUTIVE COMMITTEE. FOR ANY PARTICULARS PERTAINING TO MEETINGS CALL THE SECRETARY.

DALLAS PETROLEUM GEOLOGISTS

DALLAS, TEXAS

CHAIRMAN - - - - R. B. WHITEHEAD
ATLANTIC OIL PRODUCING COMPANY

VICE-CHAIRMAN - - ELLIS W. SHULER
SOUTHERN METHODIST UNIVERSITY

SECRETARY-TREASURER - - SAM M. ARONSON
ATLANTIC OIL PRODUCING COMPANY

MEETINGS: LUNCHEON AT 12:15, BAKER HOTEL, SECOND MONDAY OF EACH MONTH. TECHNICAL MEETINGS, 7:45 P. M., SOUTHERN METHODIST UNIVERSITY, LAST MONDAY OF EACH MONTH. VISITING GEOLOGISTS ARE WELCOME AT THE MEETINGS.

WEST TEXAS GEOLOGICAL SOCIETY

SAN ANGELO, TEXAS

PRESIDENT - - - R. L. CANNON
CANNON AND CANNON, SAN ANGELO

VICE-PRESIDENT - - JOHN EMERY ADAMS
THE CALIFORNIA COMPANY, MIDLAND

SECRETARY-TREASURER - - H. A. HEMPHILL
UNIVERSITY OF TEXAS LAND SURVEY, SAN ANGELO

MEETINGS: FIRST SATURDAY, EACH MONTH, AT 7:30 P. M., ST. ANGELUS HOTEL. LUNCHEON: THIRD SATURDAY EACH MONTH AT 12:15.

SHAWNEE GEOLOGICAL SOCIETY

SHAWNEE, OKLAHOMA

PRESIDENT - - - CLIFFORD W. BYRON
STATE NATIONAL BANK BUILDING

VICE-PRESIDENT - - - S. W. HOLMES
EMPIRE OIL AND REFINING COMPANY

SECRETARY-TREASURER - GRAYDON LAUGHBAUM
SINCLAIR OIL AND GAS COMPANY

MEETS THE FOURTH MONDAY NIGHT OF EACH MONTH AT 7:00 P. M., AT THE ALDRIDGE HOTEL. VISITING GEOLOGISTS WELCOME.

ROCKY MOUNTAIN ASSOCIATION OF PETROLEUM GEOLOGISTS

DENVER, COLORADO

PRESIDENT - - - J. HARLAN JOHNSON
COLORADO SCHOOL OF MINES, GOLDEN, COLORADO

VICE-PRESIDENT - - - C. E. DOBBIN
U. S. GEOLOGICAL SURVEY

VICE-PRESIDENT - - ROSS L. HEATON
CONSULTING GEOLOGIST, 2374 ELM STREET

SECRETARY-TREASURER - W. A. WALDSCHMIDT
COLORADO SCHOOL OF MINES, GOLDEN, COLORADO

LUNCHEON MEETINGS, FIRST AND THIRD THURSDAYS OF EACH MONTH, 12:15 P. M. AUDITORIUM HOTEL.

FORT WORTH GEOLOGICAL SOCIETY

FORT WORTH, TEXAS

PRESIDENT - - - - FORD BRADISH
JOHNSTON AND BRADISH

VICE-PRESIDENT - - - PAUL L. APPLIN
COSDEN OIL COMPANY

SECRETARY-TREASURER - PAUL M. BUTTERMORE
MID-KANSAS OIL AND GAS COMPANY

MEETINGS: LUNCHEON AT NOON, TEXAS HOTEL, FIRST AND THIRD MONDAY OF EACH MONTH. SPECIAL MEETINGS CALLED BY EXECUTIVE COMMITTEE. VISITING GEOLOGISTS ARE WELCOME TO ALL MEETINGS.

OKLAHOMA CITY GEOLOGICAL SOCIETY

OKLAHOMA CITY, OKLAHOMA

PRESIDENT - - - - R. M. WHITESIDE
SHELL PETROLEUM CORPORATION

VICE-PRESIDENT - - - G. C. MADDOX
CARTER OIL COMPANY

SECRETARY-TREASURER - - A. H. RICHARDS
RAMSEY PETROLEUM CORPORATION

RECORDING SEC'Y - HARRY LEE CROCKETT, JR.
ROGERS BROTHERS

MEETINGS: SECOND MONDAY, EACH MONTH, AT 7:30 P. M., 9TH FLOOR COMMERCE EXCHANGE BUILDING. LUNCHEONS: EVERY SATURDAY AT 12:15 P. M., 9TH FLOOR, COMMERCE EXCHANGE BUILDING. VISITING GEOLOGISTS ARE WELCOME TO ALL MEETINGS.

THE STRATIGRAPHIC SOCIETY OF TULSA

TULSA, OKLAHOMA

PRESIDENT - - - CHARLES RYNIKER
GYPSY OIL COMPANY

VICE-PRESIDENT - - - - D. C. NUFER
CARTER OIL COMPANY

SECRETARY-TREASURER - - R. C. BREHM
PRODUCERS AND REFINERS CORPORATION

MEETINGS: SECOND AND FOURTH WEDNESDAY, EACH MONTH, FROM OCTOBER TO MAY, INCLUSIVE, AT 8:00 P. M., THIRD FLOOR, TULSA BUILDING.

CHARLESTON GEOLOGICAL SOCIETY

CHARLESTON, WEST VIRGINIA

PRESIDENT - - - WILLIAM O. ZIEBOLD
517 KANAWHA VALLEY BUILDING

VICE-PRESIDENT - - - J. E. BILLINGSLEY
1108 UNION BUILDING

SECRETARY-TREASURER - - I. G. GRETTUM
306 UNION BUILDING

MEETINGS: SECOND MONDAY, EACH MONTH, AT 6:30 P. M., RUFFNER HOTEL.

Please use coupon on last page of advertisements in answering advertisers

Last Opportunity!

STRUCTURE OF TYPICAL AMERICAN OIL FIELDS

VOLS. I-II

Now PRICE, $4.00 EACH, TO MEMBERS AND ASSOCIATES

This valuable collection of geological data is increasing the enviable scientific reputation of the Association. It is a distinctive publication. Only a few of these important papers are published in the Bulletin. Members and associates now have the opportunity of securing one of these books at $4.00 per copy.

Volume I, 510 pp., 190 illus. Cloth. Price to non-members, postpaid, $5.00
Volume II, 780 pp., 235 illus. Cloth. Price to non-members, postpaid, $6.00

Soon AFTER JANUARY 1, 1932, THE PRICE OF EACH WILL BE $5.00 TO MEMBERS AND ASSOCIATES

Price to non-members: after January 1, 1932, Vol. I and Vol. II each $7.00

The American Association of Petroleum Geologists
BOX 1852, TULSA, OKLAHOMA, U. S. A.
London: Thomas Murby & Co., 1, Fleet Lane, E. C. 4

JOURNAL OF SEDIMENTARY PETROLOGY

The Journal of Sedimentary Petrology is devoted to a field in geology that is rapidly growing in importance, one that has such far-reaching scientific and economic significance that no alert geologic worker can afford to be ignorant of it. The subject matter of this Journal is the physical characters and origin of sediments. For the first time there is now offered a publication dealing solely with the processes of sedimentation, the nature and distribution of heavy minerals, insoluble residues and other constituents of sedimentary rocks, the significance of textural features,—in fact, all matters related to the genesis and later history of sedimentary formations.

The editorial staff includes leaders in America and Europe on study of the sediments:

P. G. H. Bosworth, London, England
M. A. Hanna, Houston, Texas
H. B. Milner, London, England
R. C. Moore, Lawrence, Kansas
R. D. Reed, Los Angeles, California
C. S. Ross, Washington, D. C.
A. C. Trowbridge, Iowa City, Iowa
W. H. Twenhofel, Madison, Wisconsin

The Journal of Sedimentary Petrology is now issued twice a year, in May and November. The subscription price is $3.00 per year, prepaid to addresses in the United States, Mexico, Cuba, etc.; for Canada, 20 cents additional for postage. Members of the Association may secure this Journal at $2.00 per year on becoming members of the Society of Economic Paleontologists and Mineralogists.

Send orders to

GAYLE SCOTT,
Texas Christian University, Fort Worth, Texas

NOTICE OF CHANGE IN PRICE

THEORY OF CONTINENTAL DRIFT - - ON SEPTEMBER 1, 1931, the price of this book, the edition of which is now almost exhausted, was increased FROM $3.50 TO $5.00 PER COPY.

14 authors 240 pp. 29 illus. Cloth 6x9 inches

BOX 1852, TULSA, OKLAHOMA **The American Association of Petroleum Geologists**

TRIANGLE BLUE PRINT & SUPPLY COMPANY

COMMERCIAL BLUE PRINTING
PHOTOSTATING & OIL FIELD MAPS

ENGINEERING, DRAFTING &
ARTIST SUPPLIES

Mid-Continent Representatives for Spencer, Bausch & Lomb, and Leitz Microscopes and Accessories

12 West Fourth St. Phone 9088 Tulsa, Okla.

Permian Basin Transverse Sections » »

Two Stratigraphic Cross Sections of West Texas Permian Basin from Culberson County to Jones County. Made from examination of outcrops and well samples. Printed on paper suitable for additional notations. Folded to *Bulletin* size in paper covers. These are reprints from "Transverse Section of Permian Basin, West Texas and Southeast New Mexico," by Lon D. Cartwright, Jr., this *Bulletin* (August, 1930).—Two sections, postpaid, $0.20.

BOX 1852, TULSA, OKLAHOMA **The American Association of Petroleum Geologists**

Photographic maps covering over 30,000,000 acres have been made by us and used by geologists.

Maps are now available for sale covering nearly 20 per cent of the state of Texas.

WRITE US for DETAILS on EXISTING MAPS or ABOUT NEW MAPPING

EDGAR TOBIN AERIAL SURVEYS
SAN ANTONIO, TEXAS

BULLETIN ADVERTISERS

	PAGE
American Askania Corporation	Inside back cover
American Institute of Mining and Metallurgical Engineers	vi
Baker Oil Tools, Inc.	Inside front cover
William M. Barret, Inc.	
Gebrüder Borntraeger	ii
Economic Geology Publishing Company	viii
Elliott Core Drilling Company	i
Hughes Tool Company	Outside back cover
Journal of Sedimentary Petrology	xviii
E. Leitz, Inc.	ii
W. C. McBride, Inc.	viii
McGraw-Hill Book Company, Inc.	iii
Mid-West Printing Company	v
Oil Weekly	iv
Revue de Géologie	viii
Scientia	
Spencer Lens Company	v
Sperry-Sun Well Surveying Company	iii
Edgar Tobin Aerial Surveys	xix
Triangle Blue Print and Supply Company	xix
Tulsa Chamber of Commerce	vii

PROFESSIONAL CARDS

	PAGE		PAGE		PAGE
Donald C. Barton	xiv	Edwin B. Hopkins	xiii	Dabney E. Petty	xiii
Brokaw, Dixon, Garner & McKee	xiv	Hudnall and Pirtle	xv	John L. Rich	xiv
Frederick G. Clapp	xiii	Huntley and Huntley	xiii	John Howard Samuell	xiv
Willard W. Cutler, Jr.	xiii	G. Jeffreys	xiii	Walter Stalder	xv
E. DeGolyer	xiv	Fred H. Kay	xiv	Torsion Balance Exploration Co.	xiii
Alexander Deussen	xiv	Laughlin-Simmons & Co.	xiv	Chester W. Washburne	xiii
Fort Worth Laboratories	xiii	George C. Matson	xiii	Carroll H. Wegemann	xiv
Frederick W. Garnjost	xiv	Phillip Maverick	xiv	Karl Etienne Young	xiv
Paul P. Goudkoff	xv	Leon J. Pepperberg	xv		

GEOLOGICAL SOCIETIES

	PAGE		PAGE		PAGE
Charleston	xvii	North Texas	xvi	Shreveport	xvi
Dallas	xvii	Oklahoma City	xvii	Stratigraphic	xvii
Fort Worth	xvii	Panhandle	xvi	Tulsa	xvi
Houston	xvi	Rocky Mountain	xvii	West Texas	xvii
Kansas	xvi	Shawnee	xvii		

Please use this REQUEST COUPON. Check items desired.

To The American Association of Petroleum Geologists Bulletin Advertiser

(Name and address) .....

Please send me (check desired item):

☐ Information about ..... ☐ List of publications

☐ Your catalog ☐ Price of .....

☐ Copy of ..... ☐ .....

From The American Association of Petroleum Geologists Bulletin Reader

(Name) .....

(Address) .....

Please use coupon on last page of advertisements in answering advertisers

Progress in Geophysical Prospecting » »

In spite of the depressed conditions, continued progress is being made in geophysical work. A significant feature of this progress is that methods once considered of limited application are now gaining ground due to the greater care taken in field surveys, valuable data accumulated, and improvements on the equipment. We will be pleased to furnish further details on:

Askania Torsion Balances, improved types,
Askania Pendulum Apparatus, new designs,
Askania Seismographs, mechanical and electrical,
Askania Magnetometers, vertical and new horizontal model, with new magnet system,
Askania Earth Inductors, portable field type, and various auxiliary apparatus.

AMERICAN ASKANIA CORPORATION
HOUSTON, TEXAS CHICAGO, ILLINOIS

One of the
Most Complete
Laboratories in the
Industry Protects the
High Standard of Quality
of » » »

HUGHES TOOLS

▼Hughes Rock Bits
▼Hughes Core Bits
▼Hughes Tool Joints
▼Hughes Valves

Sold by
Supply Stores
Everywhere

Hughes Tool Company

Main Office and Plant
HOUSTON - TEXAS

SERVICE PLANTS
Los Angeles
Oklahoma City

EXPORT OFFICES
Woolworth Building
New York City